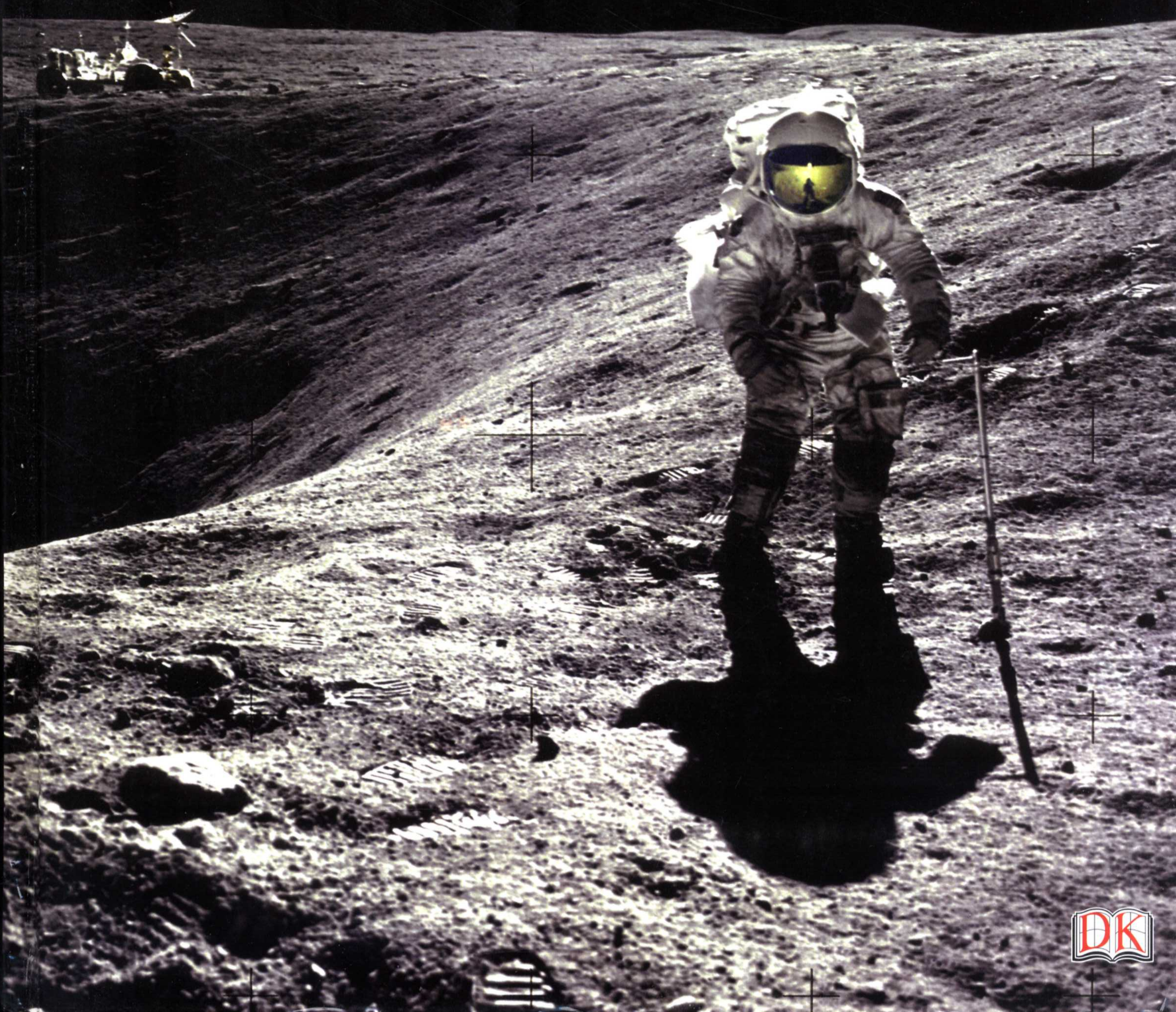
foreword by

BUZZ ALDRIN

SPACEFLIGHT

THE COMPLETE STORY FROM **SPUTNIK** TO **SHUTTLE** AND BEYOND



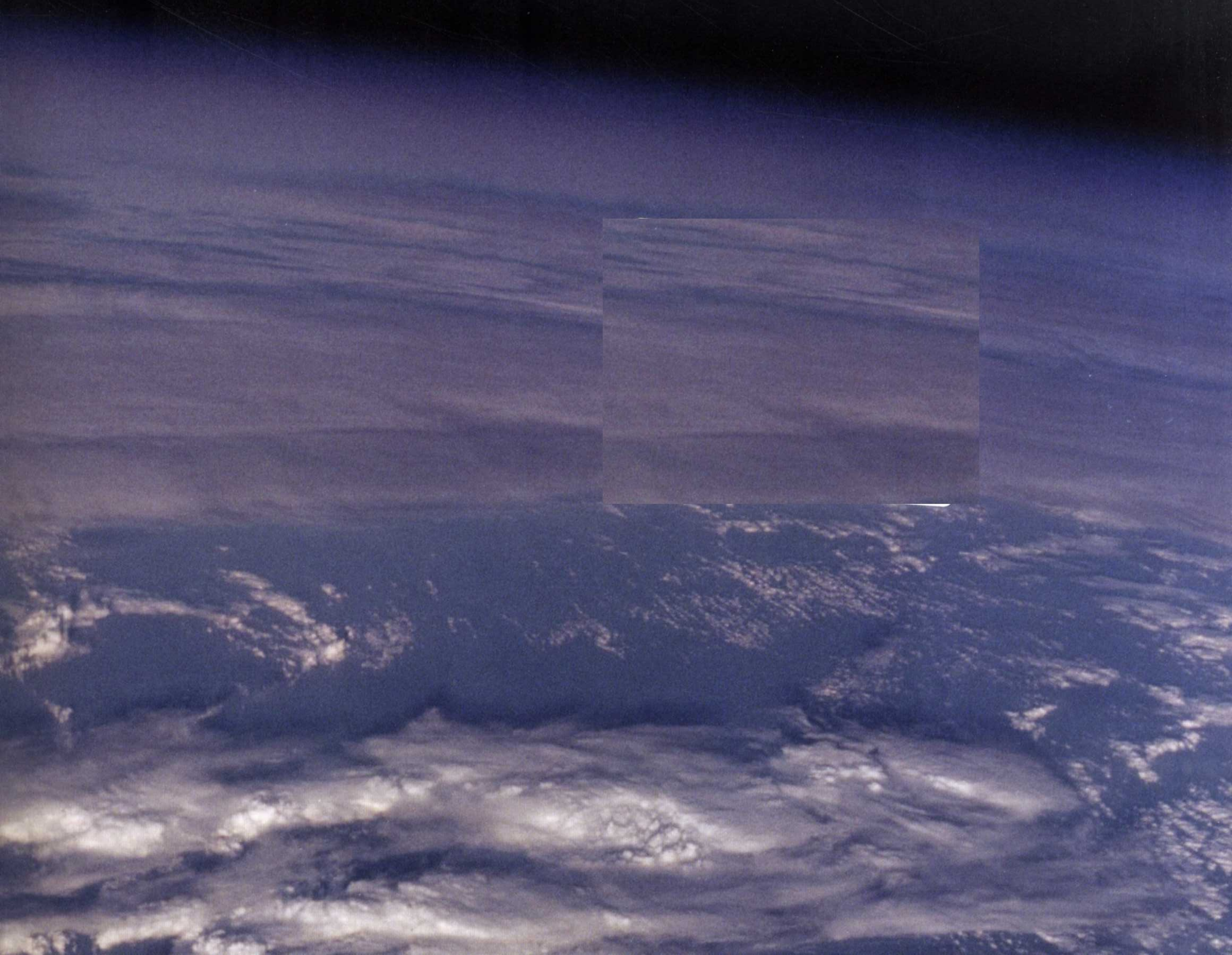
DK

DK

SPACEFLIGHT

THE COMPLETE STORY FROM **SPUTNIK** TO **SHUTTLE** AND BEYOND

GILES SPARROW



LONDON, NEW YORK, MELBOURNE,
MUNICH AND DELHI

SENIOR EDITOR Peter Frances
DTP DESIGNER Laragh Kedwell
PRODUCTION Elizabeth Warman
JACKET DESIGNERS Lee Ellwood, Duncan Turner

MANAGING EDITOR Sarah Larter
SENIOR MANAGING ART EDITOR Philip Ormerod

PUBLISHING MANAGER Liz Wheeler
PUBLISHER Jonathan Metcalf
ART DIRECTOR Bryn Walls

EDITORIAL CONSULTANT Carole Stott
INDEXER Hilary Bird

MP3 DESIGN AND EDITORIAL SERVICES

PROJECT EDITOR David Preston
ART EDITOR Jerry Udall
DESIGNERS Gadi Farfour, Peter Laws, Colin Tilley-Loughrey
ASSISTANT EDITORS Joe Booker, Emma Northam
PICTURE RESEARCHERS Ieva Augustaityte, Marian Pullen
ILLUSTRATORS Julian Baum, Peter Bull, Hugh Johnson, Ian Palmer, Chris Taylor, Adrian Thompson, Terry Pastor (The Art Agency)
CONSULTANT Robin Scagell
SPECIAL PHOTOGRAPHY Gary Ombler

CONTENTS

First published in Great Britain in 2007
by Dorling Kindersley Limited
80 Strand, London WC2R 0RL

A Penguin Company

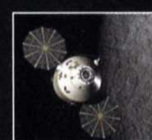
2 4 6 8 10 9 7 5 3 1

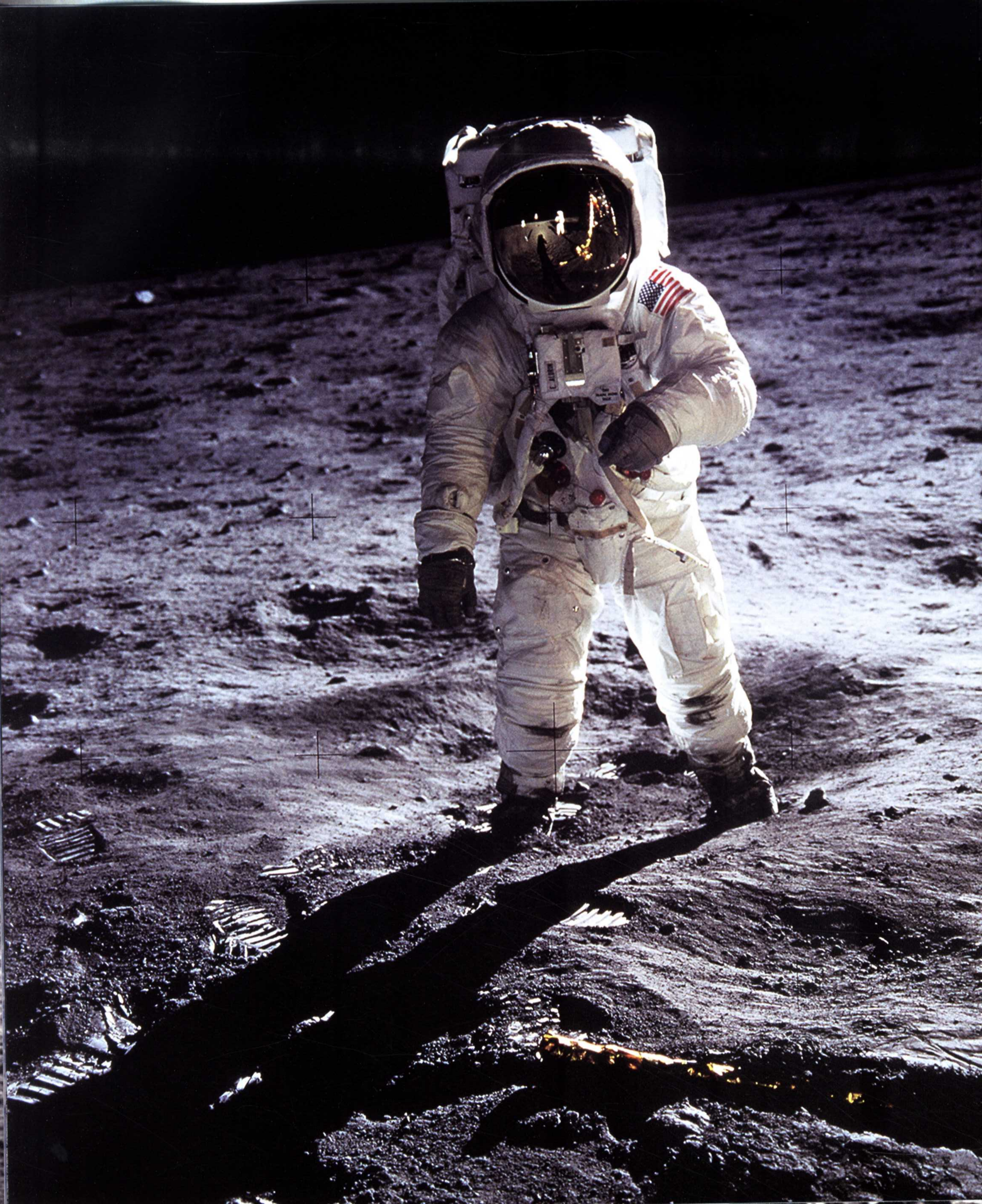
A CIP catalogue record for this book is available from the British Library

ISBN: 978-1-4053-1818-1

Colour reproduction by GRB, Italy
Printed and bound in China by Hung Hing

See our complete catalogue at
www.dk.com





50 years and counting

By Buzz Aldrin

The Apollo 11 moonwalk was the first time that humans had set foot on another world. It was the symbolic highlight of the whole Apollo programme, but the credit for it should be shared widely. That first landing would not have been possible without the astronauts who flew the earlier exploratory missions. For example, before we could establish that a landing was possible at all, we had to send two especially hazardous missions, Apollo 8 and Apollo 10, into orbit around the Moon. In fact, it was not until Apollo 13 came close to ending in disaster that we realized just how much danger the astronauts on those earlier missions had been in. Yet, when I talk to anyone about the Apollo programme, one of the first questions they usually ask is, "How many people walked on the Moon?" I have to give them the answer – 12. However, it should not be forgotten that, in all, 24 men left Earth orbit (a feat that has not been repeated since) and went to the Moon.

As well as the other astronauts, we also owe a great debt to the many thousands of people who were involved on the ground. Since leaving NASA, I have tried to continue to play an active part in the future of space exploration, and some of the pioneering engineers who worked on the Apollo programme continue to inspire me in that work.

In one way or another, I have now been involved in the manned exploration of space for more than 40 years – that is to say, for almost the entire duration of the Space Age and a large part of the period covered by this book.

It is generally accepted that the Space Age began when the Soviet Union sent the satellite Sputnik 1 into orbit on 4 October 1957. I have to be honest and say that at the time Sputnik did not make a great impression on me. I have my reasons, though. At the time, the United States was in the thick of the Cold War with the Soviet Union. As a pilot in the United States Air Force, I was stationed in West Germany, where I was training to fly tactical fighters to send nuclear weapons into the Soviet Union. In the event that a nuclear exchange did break out, it was unlikely that I would have a base to return to. That was a sobering reality for a 28-year-old with a young family. When Sputnik went into space and sent back its radio signal, it seemed to me little more than a stunt.

It was different when Yuri Gagarin became the first person to fly in space, in April 1961. By then, my own circumstances had changed. I was halfway through a doctoral thesis on piloting techniques for space rendezvous. In those early years of the Space Age, one thing quickly led to another. Less than a month after Gagarin's return, Alan Shepard made his sub-orbital flight,

"Walking on the Moon was **a piece of cake.** It was easy. But getting to the Moon was anything but easy."

FIRST STEPS ON A NEW WORLD
This photograph of me was taken by Neil Armstrong in the Sea of Tranquillity. I'm leaning forward slightly, to avoid overbalancing under the weight of my backpack, and smudges of moondust can be seen on my shins because I misjudged the distance between the bottom step of the ladder on the Lunar Module and the surface. But on the whole, it was easy to walk around on the Moon. Those first steps attracted a lot of attention – understandably, because of the symbolism of the event – but from a technical point of view this was one of the easiest parts of the mission.

becoming the first American in space. And just 20 days after that, President Kennedy made his famous speech committing our country to send a man to the Moon – and bring him safely back to Earth – before the end of the decade.

All this time, I was drawing closer to taking an active part in the space programme. By the end of 1962, I had finished my thesis, and in October of the following year I accepted an invitation from the Head of the Astrounaut Office, Deke Slayton, to join the astronaut programme. The tensions between East and West remained high, but it is also undoubtedly true that the Cold War gave a great impetus to the speed of development in spaceflight. As we pursued our own Mercury, Gemini, and then Apollo programmes, we knew that the Soviets were training their own people to fly in space and that they had some extremely capable engineers, men such as their Chief Designer, Sergei Korolev.

As we embarked on the Gemini programme, I was able to put my earlier studies of space rendezvous to use. It was clear that to make a landing on the Moon we would need spacecraft made up of modules that could separate from one another and then link up again, either in orbit around the Earth or around the Moon. I was able to contribute to the development of the techniques that were used to do this. I was also able to help find new ways of training for spacewalks. After Michael Collins's spacewalk on Gemini 10, it was decided that we should experiment with underwater training. This is now a staple part of astronaut preparation, but it was new and untried back then. I had done some scuba diving before joining NASA, so it was an environment in which I was already at home. I was able to put both my rendezvous expertise and my underwater training into practice when I flew on Gemini 12 with Jim Lovell in 1966. During that mission, we performed docking manoeuvres and I made three spacewalks.

After Gemini came Apollo. Of course, an enormous amount has already been said and written about that programme. In retrospect, Apollo now seems remarkable to me not only for its boldness and its ultimate success but also for how much we accomplished in a short time (there were just eight years between the announcement of our intention to go the Moon and the first landing) and for how adaptable we showed ourselves to be. For example, we

A LIFE IN FLIGHT
Flying aircraft and flying spacecraft are very different experiences. In space, the pilot usually has less control and relies more on computers and help from the ground. I began my own flying career in the Air Force and flew in combat in the Korean War (above). In all, I spent 290 hours in space, about five of them outside the Gemini 12 spacecraft (below).

"I remember this fleeting thought from the surface of the Moon: the two of us, Neil and I, are **further away** than two humans have ever been before, not just in distance but in what we have to do to get back, and yet there are **more people paying attention** to what we are doing now than have ever paid attention to other people before."

THE NEXT STEPS
When I took this photograph of my own footprint, I had little idea that it would become a symbol of human exploration in space. It is now 35 years since we left the Moon. Although it seems that it will be at least ten years before another astronaut leaves their mark there, it is still encouraging to know there is now a firm plan to go back.

recovered very quickly from the awful fire on Apollo 1. Apollo 8 also comes to mind again. This was the first manned mission into lunar orbit, so it was a big step forwards but it was one that we had to make sooner than we had originally planned because we suspected that the Soviets were gaining ground on us and were about to attempt their own circumnavigation of the Moon.

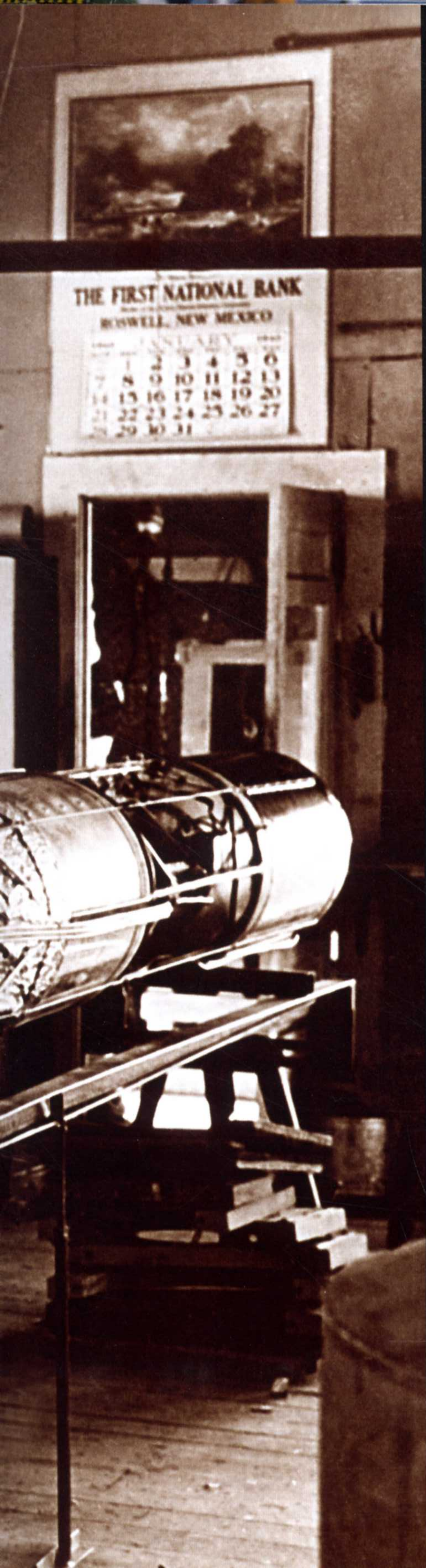
When we look back over humanity's first 50 years in space, it is important that we not only celebrate what we have done but also properly understand the past, seeing clearly where mistakes have been made, so that we can plot the right course for the future.

Engendering a spirit of adaptability similar to the one we had on Apollo is something that we should be doing as we look ahead. NASA's two main projects over the last three decades have been the Space Shuttle and the International Space Station. Both are technically marvellous but they are highly ambitious and incredibly complex. Despite some successes, they have not lived up to all their expectations. One way to make ourselves more adaptable in future is to have several projects running along parallel paths. The main US project for the future is Orion. We need to develop the best possible solution for this programme, because it will ultimately provide us with the technology to return to the Moon, scheduled for the end of the next decade. But in parallel with this, I think that we should have a plan for spacecraft to replace the Space Shuttle in low Earth orbit when it is retired from service, probably within the next five years.

In my view, spaceflight should not be an exclusive preserve of professional astronauts. I would like to see as many people as possible become involved. Ever since the Shuttle programme, there has been a widening of the net for crew selection, something that should continue and be extended. We should support opportunities for so-called "space tourists" or, as I would prefer to call them, star flyers or star travellers. This can be done by making a concerted effort to educate children about space and make it appealing to them. Education is, after all, the key to our future. I hope that this book will help to inspire a future generation of astronauts and, in some way, help to make the next 50 years of human endeavour in space as rich, exciting, revealing, and successful as the first 50.

Buzz Aldrin

JANUARY 1940: ROCKET MEN
The American rocket pioneer Robert Goddard (foreground) and his team of engineers inspect one of their newly created rockets in their workshop at Roswell, New Mexico.



ROCKET DREAMERS

FOR CENTURIES, dreams of travel into space had been the preserve of fantasists, satirists, and the occasional speculative scientist, but the 20th century changed all that. Rockets were for the first time recognized as the only practical means of space travel, while a series of design advances transformed them from outsized fireworks to intercontinental ballistic missiles. The genealogy of the space age is a complex one. Nineteenth-century novelists influenced rocket theorists such as Konstantin Tsiolkovskii in Russia, and later Robert Goddard in America and Hermann Oberth in Germany. Each made his own unique contributions to rocket science, but there were many parallel discoveries, too. In turn, these pioneers influenced another generation – most notably in Russia and Germany, where the rocket would grow from an experimental plaything to a weapon of war. In the aftermath of the Second World War, rival superpowers scrambled to adapt the secrets of German rocketry to their own purposes. But throughout all this, the engineers and scientists behind the rockets retained the dream of spaceflight.

The earliest rockets

Before spaceflight, there was the rocket – at first little more than a novelty, but later a powerful weapon of war whose importance waxed and waned over the centuries, nevertheless playing a pivotal role in several military conflicts around the world.

HERO'S ENGINE
An early reaction motor was designed in the first century AD by Greek-Egyptian scientist Hero of Alexandria. Heat applied from below boiled water in a spherical vessel, and steam spouting from the nozzles caused the sphere to spin on its axis.

Though it took some time for scientists to realize it, a rocket is a "reaction motor" operated by the simple principle of action and reaction – as fuel exhaust escapes from the rocket in one direction, the rocket is pushed in the other. The basic requirement for any rocket, then, is a propellant that can be stored in a relatively stable state, but which expands violently when required. And until the 20th century, only one thing fitted the bill: a black powder, also known as gunpowder – made up of charcoal, sulphur, and saltpetre (potassium nitrate) – that exploded when a flame was applied.

History does not record the invention of this early weapon of mass destruction, but it is thought to have originated in Song Dynasty China around the middle of the 11th century. The use of exploding powder as a propellant would have followed naturally, probably a result of seeing containers flung across the room by the force of its explosions. By 1232, self-propelled "flying bombs" were being used to defend the Chinese city of Kai'feng from the advancing Mongol army of Genghis Khan. These early rockets would have been almost as dangerous for the defenders as the attackers, since whenever any part of their flimsy paper or card wrapping burnt through to form another exhaust, they might shoot off in another direction, setting fires wherever they landed.

The new weapons, however, were not enough to save China from conquest, and by 1241 the Mongols were expanding their empire to the west, using rockets themselves in battles across Eastern Europe. And with them came the secret of black powder – the recipe was first written down around 1250 by English scholar Roger Bacon (though he disguised it in code, wary of its potential as a weapon). While the Mongol threat disintegrated in a series of internal disputes, the knowledge of black powder spread rapidly. In 1288, Arab forces were using rockets in an attack on the Spanish city of Valencia, and by 1405 rockets were a familiar part of the medieval war machine, depicted by German engineer Konrad Kyeser in his military manual *Bellifortis*.

While China now entered a more peaceful era under the Ming Dynasty, the evolution of rockets in Europe continued apace. Kyeser's rockets were already mounted on the top of long stabilizing rods, which could be placed in a gutter-like launcher to allow for basic targeting. Seventeenth-century Polish author Casimirus Siemienowicz illustrated a variety of rockets that are sometimes strikingly similar to the designs of today, with long tubular bodies, stabilizing fins, and even multiple stages (see p.23). In 1715, Russian Tsar Peter the Great's plans for a new capital at St. Petersburg included an enormous factory for

CONGREVE ROCKETS
The rockets designed by William Congreve (top) featured a number of important innovations, including stabilizing fins around their bases. Later Congreve designs were fired from copper launching tubes, which helped to direct their flight and reduced the risk of misfires during launch.

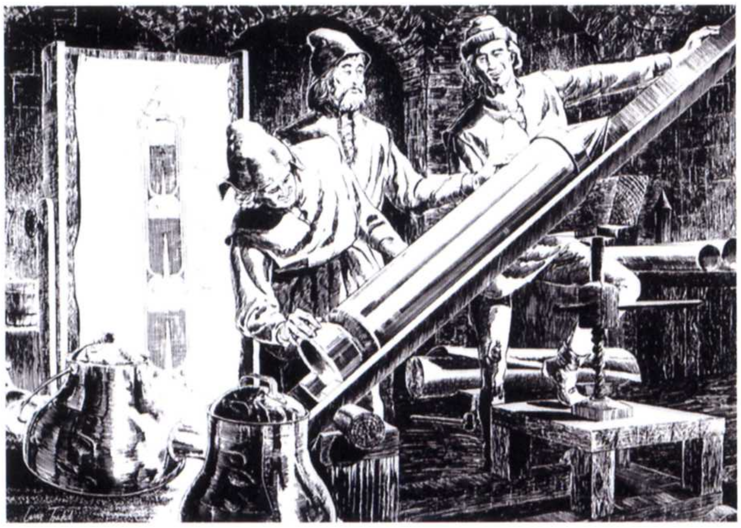
WAN HU'S ROCKET CHAIR
One often-told story of early Chinese rocketry is the legend of Wan Hu, a Ming-Dynasty official who supposedly flew into space using a chair supported on 47 rockets.

ROCKETS AT WAR
One key element in the popularity of rockets was their portability. Congreve rockets could be moved, set up on their launching frames, and fired with relative ease, even from small unstable platforms such as boats. This painting depicts an attack by the British on the American fleet during the War of 1812.

the mass production of rockets. But in truth, the rocket was on the verge of obsolescence, thanks to the increased range and accuracy of artillery.

The metal-clad rocket

The invention that "saved" the rocket in the 18th century once again emerged from the East – this time from India. Around the mid-1700s, Hyder Ali, Sultan of Mysore, ordered the construction of rockets sheathed in iron, not card or paper. Because the heavier cladding directed the rocket's exhaust more efficiently and would not burn through, the new rockets had a vastly increased range of more than 800m (½ mile), despite their greater weight. By the late 18th century, as the British grip on India tightened, Ali's son Tippu Sultan put his father's invention to good use in the sieges of Seringapatam (1792 and 1798), though rockets were not enough to save him from eventual defeat. In fact, they ultimately helped his enemy, since captured rockets shipped back to Britain probably inspired William Congreve, working at the Royal Arsenal, to develop a more advanced model. Congreve gave his rockets a payload, or cargo, for the first time, mounting a separate charge of black powder in the rocket's nose, where it would explode on impact – the first warhead. He also invented an improved launching platform and came to realize that a ring of five smaller exhaust nozzles gave a rocket much more stability than a single outlet.



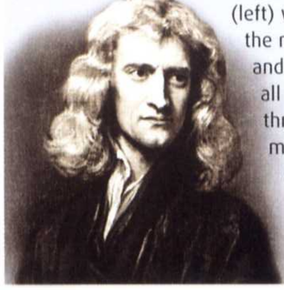
ADVANCED ROCKETRY
This illustration shows armourers constructing a rocket to the plans of Casimirus Siemienowicz. In his time, the study of ballistics, allowing flight paths and targets to be calculated, was advancing rapidly.

The 19th century saw a series of modifications to Congreve's design. In 1807, Henry Trengrouse devised a rocket that could carry a line to a ship in difficulties, which soon became an important part of coastguard equipment in Britain and beyond. Shortly after this came the invention of the rocket-powered harpoon and the signal flare. The most important advance, though, came in 1844 when Englishman William Hale tilted the exhaust nozzles of his designs, causing the rockets to rotate around their long axes and fly with greater stability. This meant that the clumsy stabilizing stick could at last be eliminated.

TECHNOLOGY

LAWS OF MOTION AND GRAVITY

Until the late 17th century, philosophers were resigned to the idea that the Universe was driven by supernatural, or at best inscrutable, forces, with little relationship between the behaviour of objects on Earth and those above. This view began to change around 1609, when Johannes Kepler finally swept aside old notions of heavenly spheres and celestial clockwork, replacing them with laws of planetary motion that could accurately describe (though not explain) the orbits of the planets. However, it was the English scientist Isaac Newton (left) who finally showed how the movement of the planets, and of objects on Earth, could all be explained through three simple laws of motion, and the effects of a force he called gravity that was produced by any object with a substantial mass.



Space visionaries

Writers have fantasized about journeys beyond Earth since classical times, but the industrial revolution of the 19th century, coupled with advances in scientific knowledge, gave rise to a wave of speculative fiction that would inspire later generations to make space travel a reality.

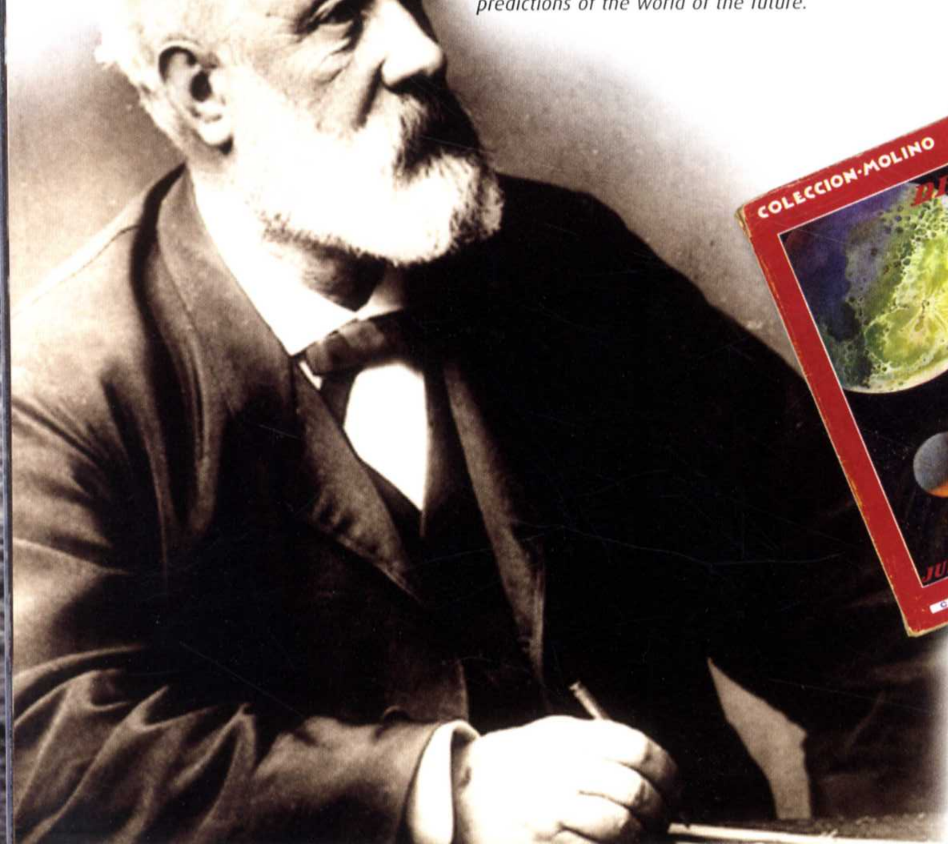
WEIGHTLESS BLUNDER
Jules Verne's travellers experienced weightlessness only as they crossed the region where the Earth and Moon's gravitational pull were balanced. In reality, though, since they and their ship were travelling at constant speed, they would have been weightless immediately after launch.

The Roman poet and satirist Lucian of Samosata is widely acknowledged as the world's first science-fiction writer. His *True History*, written around AD 150, is a tale of travellers carried into space and eventually to the Moon on a giant water spout. Lucian, however, was principally writing a fantasy, at a time when the rigours of space travel were purely matters of guesswork. Later literature throws up similar tales, such as the proposal by the 17th-century English bishop Francis Godwin for a lunar expedition in a carriage pulled by geese; a more thoughtful fantasy comes from no less an authority than Johannes Kepler, the astronomer who finally worked out the laws of planetary orbital motion and clinched the case for a Sun-centred Solar System. In his *Somnium* (Dream) of 1634, Kepler tells the tale of an expedition to the Moon, recognizing that it would involve a traumatic launch and travel beyond Earth's atmosphere and that conditions in space were dangerous, with fierce radiation from the Sun.

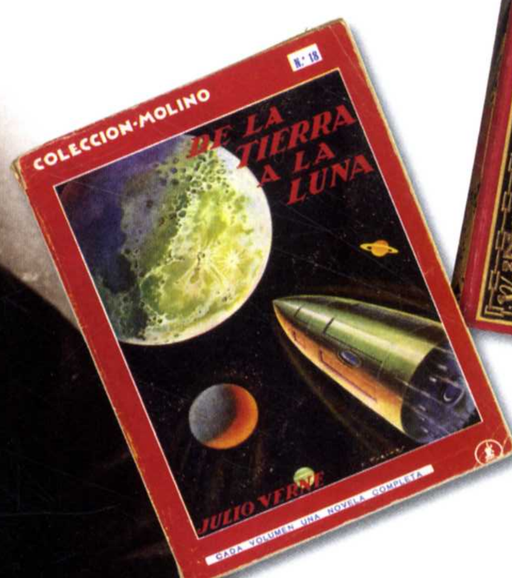
BULLET TO THE MOON
Although this illustration for From the Earth to the Moon *implies some kind of engine driving the moonship, Verne never wrote of such a device.*

Verne and Wells

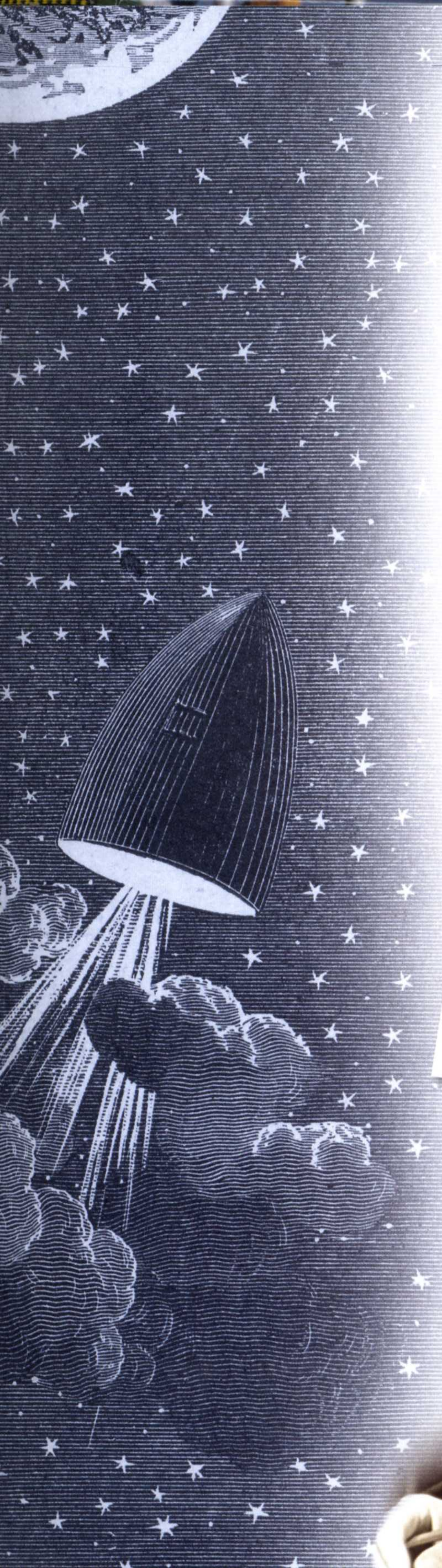
However, the true colossi of science fiction belong to the 19th century. French author Jules Verne wrote a series of adventure novels on scientific themes, of which the most influential was *From the Earth to the Moon* (1865). Verne made a serious attempt to address the problem of launching a spacecraft towards the Moon, opting to propel his heroes and their moonship from a giant cannon, the *Columbiad*. His understanding of the laws of physics was somewhat awry, though: he didn't realize that the ship's occupants would be crushed by the sudden acceleration as the shell was fired (something that Kepler had taken into account); and he misinterpreted the influence of gravity (see caption, above left). In contrast, Herbert George Wells made little or no attempt at realism in his story of lunar flight. In *The First Men in the Moon*, written a generation later in 1901, he solved



JULES VERNE
In a prolific career, Verne wrote 54 novels and numerous short stories. He frequently returned to the theme of exploration in unknown environments and to making predictions of the world of the future.



EARLY EDITIONS
From the Earth to the Moon *(left) and its sequel,* Around the Moon, *were the bestsellers of their age, published in many languages and rarely out of print.*



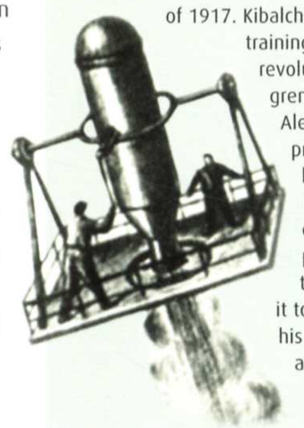
the problem of space travel by having one of his characters invent a material, cavorite, that blocks out the effects of gravity. What's more, when the spacecraft's cavorite coating is complete, it simply shoots into the sky without any apparent propulsion. However, while Verne's story was focused on the human characters and the voyage to the Moon itself, Wells's imagination can be forgiven, since in his case space travel was largely a means to an end. Once on the Moon, the story turns into a political allegory as the travellers encounter a strange alien society. (In his even more influential *The War of the Worlds* (1898), Wells's Martians seem to use a "space cannon" to fire their ships towards Earth.)

Both Verne's and Wells's errors would have been obvious to anyone well-versed in the physics of the time, but a generation later educated people were still criticizing the pioneers of rocketry and claiming that space travel was impossible – at a time when it was on the verge of becoming a reality. The old geocentric instincts died hard, and there seems to be something about the laws of motion and gravitation that makes them particularly susceptible to misunderstanding.

BIOGRAPHY

NIKOLAI KIBALCHICH

Rocket-powered spaceflight was suggested more than once in the 19th century, but the strangest case must surely be the tale of Nikolai Kibalchich (1853–81). In the 1880s, Russia was an absolute monarchy ruled by the Tsar and his noblemen, and the lower classes were seething with the resentment that would eventually lead to the revolution of 1917. Kibalchich, an engineer by training, became involved in a revolutionary group and made grenades used to kill Tsar Alexander II in 1881. While in prison awaiting execution for his role in the assassination, Kibalchich sketched a design for a rocket-powered passenger platform similar to that shown here. He sent it to the government, but after his death it languished in the archives until its rediscovery in 1917.



Despite these problems, Wells, Verne, and others that followed them helped shape the imaginations of a generation of scientists. Space travel no longer seemed a fantastical dream, but an attainable goal. At least in some circles, one could now discuss the issues seriously and without risk of mockery.

THE MOONSHIP
In this illustration, Mr. Bedford, narrator of The First Men in the Moon, *helps Dr. Cavor to fit panels of gravity-resistant cavorite onto his ball-shaped spacecraft.*

H.G. WELLS
While Jules Verne was primarily interested in telling scientific adventure stories, H.G. Wells was a more political writer, frequently using his novels about the future to promote his socialist beliefs.

Rocket prophet

Konstantin Tsiolkovskii did more than any other single person to make space travel a reality, developing many of the techniques and principles still used in rocketry today. Yet he spent most of his life as an obscure provincial teacher, winning recognition only in his old age.

While Verne and Wells had made the subject of space exploration acceptable, it was left to other talents to make it achievable, and the greatest of these was undoubtedly Konstantin Eduardovich Tsiolkovskii. Born in 1857 in the Russian town of Izhevskoye, Tsiolkovskii overcame a childhood illness that left him almost entirely deaf, to become one of the greatest practical scientific thinkers of his time.

> "From the moment of using **rocket devices** a new great era will begin in astronomy."
>
> **Konstantin E. Tsiolkovskii, 1896**

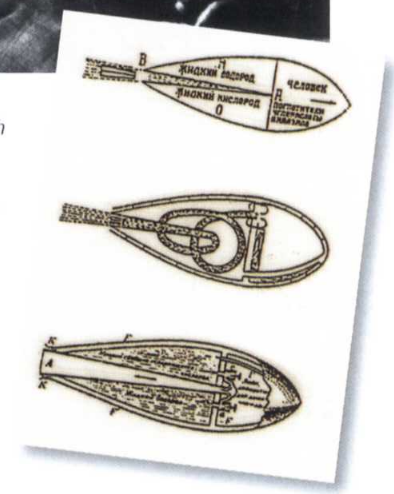
Fascinated from an early age with airships and balloons, Tsiolkovskii came to believe that a sealed ship of this type might be suitable for space travel. By this time, most scientists had realized that space beyond Earth was a vacuum – balloon-borne experiments had shown that air pressure fell rapidly at high altitudes. Since most propulsion systems relied on the presence of a medium to push against, they would be useless in a vacuum, so how could a spacecraft be propelled and steered?

A high-speed launch from a Verne-style cannon was out of the question. Tsiolkovskii carried out experiments that showed living creatures could survive an acceleration of up to 60m/s (200ft/s) per second (roughly six times the acceleration due to Earth's gravity, or 6*g*), but not much more. He also worked out the Earth's escape velocity, the speed required to launch an object from the Earth's surface so that it could never be pulled back by the planet's gravity. This turned out to be about 11.2km (7 miles) per second. Clearly any attempt to reach such a speed in a near-instantaneous burst of acceleration would result in a spacecraft's occupants being crushed to death.

The solution, Tsiolkovskii suggested, was a self-contained rocket or "reaction engine", which could produce steady acceleration inside or outside the atmosphere, eventually reaching speeds where a spacecraft could remain in orbit – its tendency to move away from the Earth perfectly balanced against the force of the planet's gravity – or even break free of the Earth altogether to travel across interplanetary space. Tsiolkovskii was not actually the first person to suggest rockets as a means of space travel (that honour goes to the 17th-century French author Savinien Cyrano de Bergerac), but he was the first to treat the idea seriously, publishing a number of detailed scientific papers that reached fruition in *The Exploration of Cosmic Space by Means of Reaction Devices* (1903).

Among Tsiolkovskii's breakthroughs was the realisation that multi-stage rockets would be more efficient than single-stage ones (see p.23). He was also the first to show how steering vanes, used to deflect the exhaust, could control a rocket's direction in a vacuum. Tsiolkovskii was certain that liquid fuels would be needed to reach space, since black powder (see p.12) was too weak a propellant, and combusted only by reacting with oxygen in the atmosphere. A truly self-contained rocket would have to carry not only fuel, but also a chemical oxidant, in tanks onboard, and the best choice would be liquid hydrogen fuel burning with liquid oxygen. At the time, however, these substances were impossible to manufacture in large amounts.

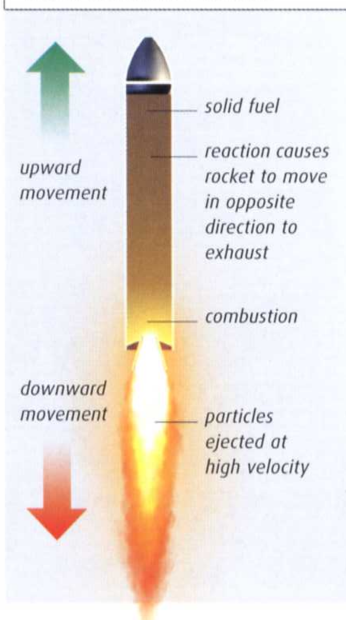
THE INVENTOR'S WORKSHOP
While working as a teacher in the town of Kaluga, Tsiolkovskii produced numerous models to demonstrate his ideas, but never attempted to launch a rocket himself.



GRAND OLD MAN
Tsiolkovskii spent much of his life in relative obscurity. It was only after the 1917 Russian Revolution that his ideas, such as liquid rocket designs (right), received widespread recognition. When he died, in 1935, he was acknowledged as the pioneer of a new science.

TECHNOLOGY

HOW ROCKETS WORK



Rockets rely on the principle of conservation of momentum – the immutable law that says that unless an external force is applied, the momentum of a system (its mass multiplied by its velocity, or speed in a particular direction) must stay the same. So when the exploding fuel inside a typical rocket forces gas out of the exhaust at high speed, the rocket itself must move in the opposite direction in order for the overall momentum to stay the same. Because the rocket has far more mass than the exhaust gas, it accelerates far more slowly than the exhaust. Once it has left the Earth's atmosphere, the rocket can work equally well, if not better, in a vacuum.

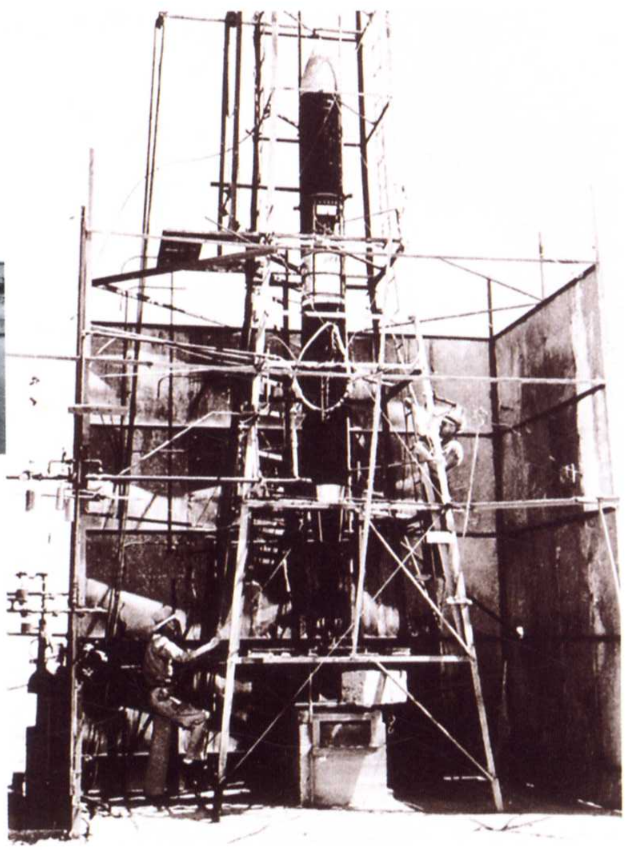
New World pioneer

Although Konstantin Tsiolkovskii is rightly acknowledged as the founder of modern rocketry, many of his ideas were unknown to contemporaries such as Robert Goddard, the American physics lecturer who, in 1926, heralded a revolution with his launch of the first liquid-fuelled rocket.

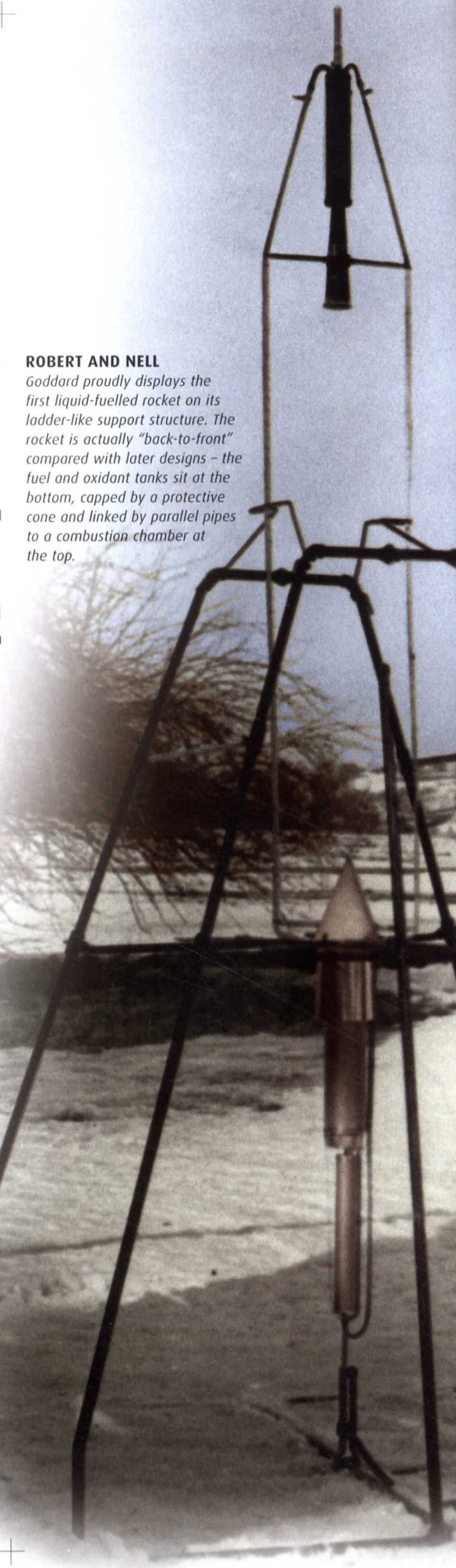
Born in Worcester, Massachusetts, in 1882, Goddard was fascinated by physics from an early age, though his interest in spaceflight was not ignited until 1898, when he read H.G. Wells's *The War of the Worlds*. Lagging behind his schoolmates due to constant illness, Goddard nevertheless pursued his studies, which took him as far as a research fellowship at Princeton before a near-fatal bout of tuberculosis in 1913 forced a return to Worcester. Once recovered, he took a teaching post at nearby Clark University, where he had studied for his doctorate and where he would remain for the next 20 years.

Goddard realized the potential efficiency of liquid fuels in 1909 (independently of Tsiolkovskii), but his convalescence at Worcester must have inspired him to act, since it was shortly after this, in 1914, that he began to register patents for rocket designs, including a multi-stage vehicle and a liquid-fuelled rocket. Unlike Tsiolkovskii's theoretical mix of liquid hydrogen and liquid oxygen, Goddard's combination of gasoline for fuel and liquid nitrous oxide for oxidant (see panel, opposite) was practical, using the technology of the day. Once back at work, he began developing working engines, initially funding his own experiments, but later with backing from the Smithsonian Institute and, once the United States had become involved in the First World War, the Army. Experiments using small charges of solid fuel led him to discover the optimum design of rocket nozzle – a shape first proposed by Swedish engineer Gustav de Laval in 1890 for use in steam engines. Although Goddard demonstrated an early form of bazooka, the war ended before he could put many of his theories into practice.

In 1919, Goddard summarized his work so far in his book *A Method of Reaching Extreme Altitudes*. For many outside Russia, this was the first serious

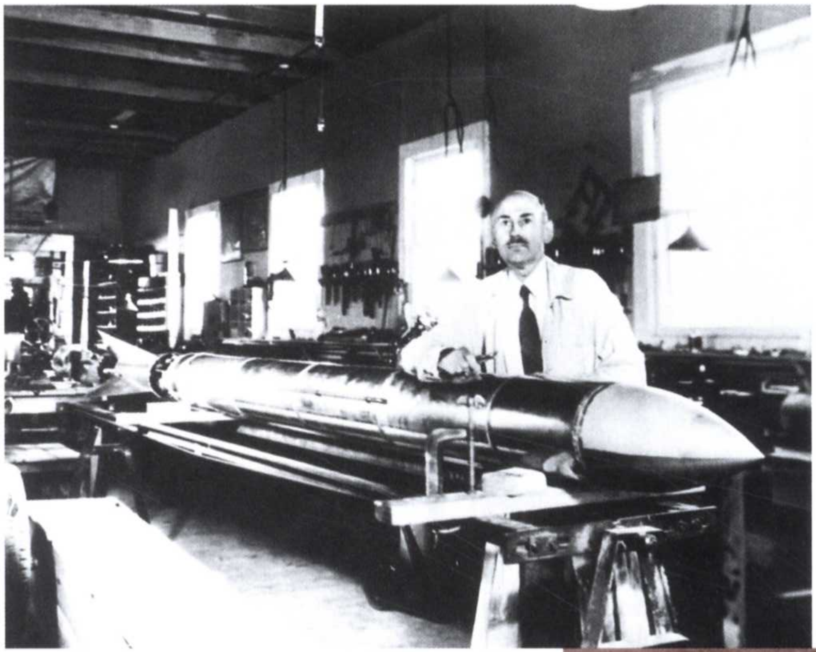


BIGGER AND BETTER
Goddard's rockets developed rapidly, from early tabletop models (above), through Nell, to larger, advanced designs, such as his P-series of the early 1940s (right). By this time, components were arranged in a more familiar order, with fuel tanks, topped with an aerodynamic nosecone, sitting on top of the combustion chamber.



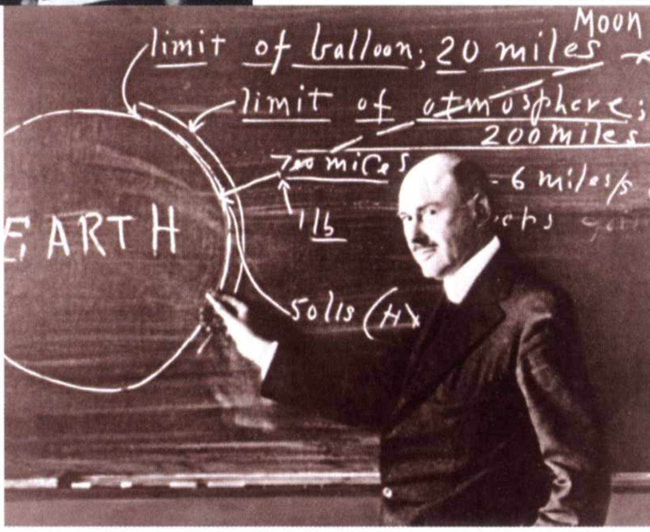
ROBERT AND NELL
Goddard proudly displays the first liquid-fuelled rocket on its ladder-like support structure. The rocket is actually "back-to-front" compared with later designs – the fuel and oxidant tanks sit at the bottom, capped by a protective cone and linked by parallel pipes to a combustion chamber at the top.

> "... the dream of yesterday is **the hope of today** and the reality of tomorrow."
>
> **Robert Goddard, 1904**



WORK AT ROSWELL
By 1940, Goddard was working on more advanced rocket designs at his Roswell laboratories. This design was one of the first to use turbopumps to force fuel into the combustion chamber at a high rate.

SPACEFLIGHT ADVOCATE
The most famous portrait of Goddard dates from 1924 and shows him at the blackboard at Clark University, discussing the possible use of rockets to reach the Moon. Unfortunately, Goddard's promotion of such ideas led to merciless teasing by the press.



proposal for space travel they had encountered, and Goddard had to endure a great deal of scorn, often from journalists who delighted in attacking his ignorance of basic physics when, in fact, they were revealing their own. One *New York Times* article of January 1920 was particularly withering, though the paper eventually saw fit to issue a retraction in 1969, on the day after the Apollo 11 Moon landing.

Nell takes flight

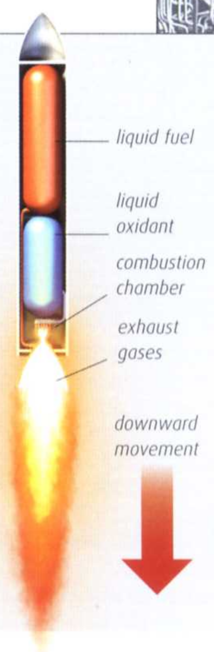
Despite all this, Goddard persevered, and on 16 March 1926, he saw his liquid-fuelled rocket, nicknamed Nell, take flight for the first time. The flight lasted only two and a half seconds and reached a height of 13m (41ft), but the principle had been proved.

By the late 1920s, the regular launches from Worcester were attracting a lot of attention. Goddard wanted more privacy, and through his friendship with aviator Charles Lindbergh (the first man to fly across the Atlantic), he attracted funding from financier Daniel Guggenheim that allowed him to relocate to Roswell, New Mexico. Here, he continued to improve his rockets until his death in 1945, and also worked on experimental aircraft for the US Navy. His attempts to recapture Army interest were met with indifference, though his work found a more appreciative audience in Europe – Germany even attempted to plant spies among his researchers.

TECHNOLOGY

LIQUID-FUELLED FLIGHT

Liquid fuels are far more efficient than the black powder used in rockets before Goddard's time, but they have a number of inherent risks, since the chemicals they use are sometimes highly unstable and difficult to manufacture or store. While the fuels will frequently react with oxygen in the air, in order to be self-contained a rocket must carry a chemical oxidant onboard. As shown here, fuel and oxidant are carried in separate tanks, and travel through a network of pipes to reach the combustion chamber, where they may either react spontaneously, or require a spark in order to explode. Although modern solid-fuel rockets are far more efficient than their black-powder ancestors, liquid-fuel designs retain one key advantage – the rate of burn can be throttled up and down, and even stopped and restarted later.



The dream takes shape

While much of the groundwork for modern rocketry was laid in Russia and America, it was in Germany that the idea of space travel really took hold. In the early 20th century, visionaries planted the seeds that would ultimately give rise to the rocketry programs of the Second World War.

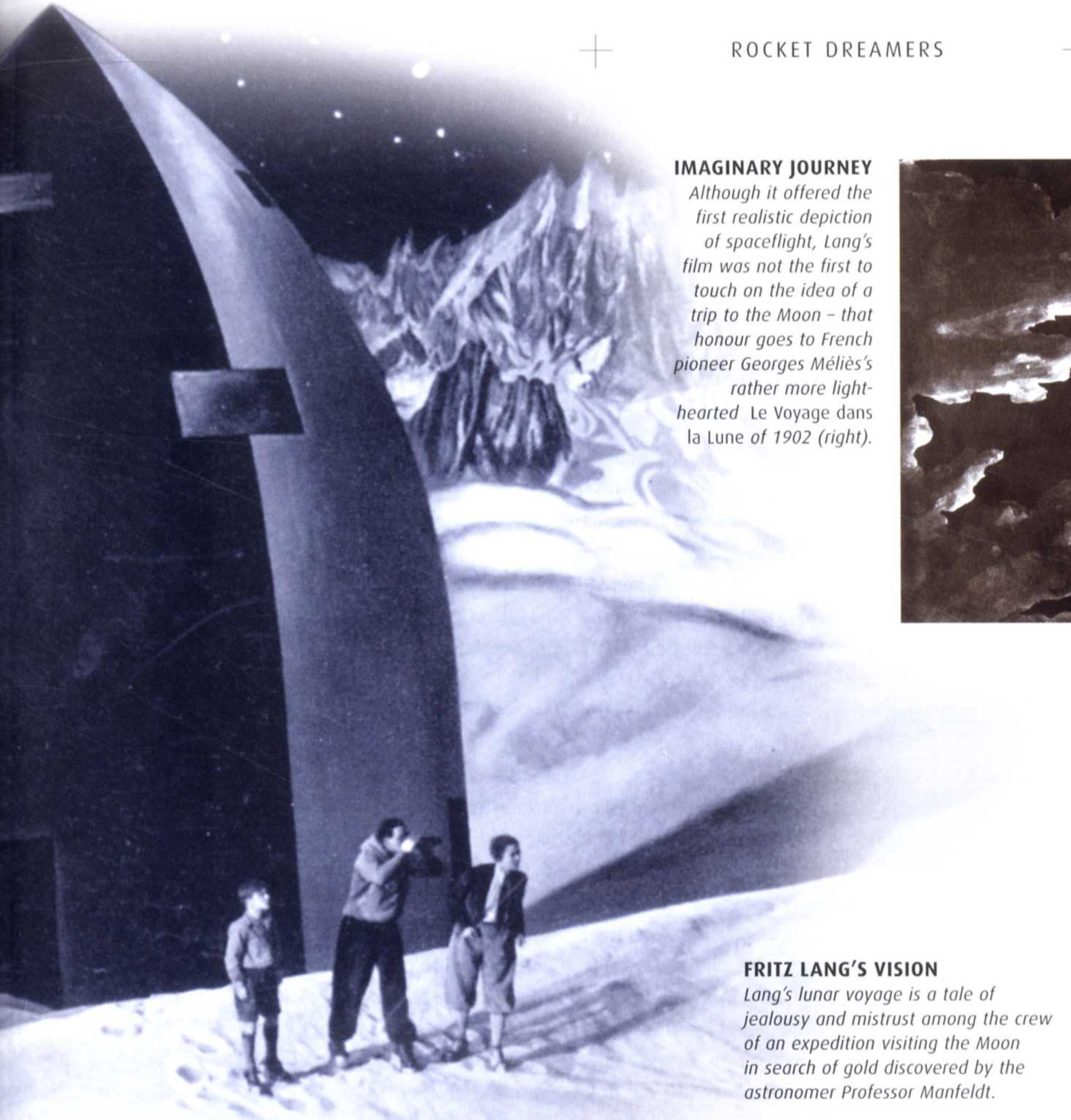
LIFE ON THE MOVE
Born in the Austro-Hungarian city of Hermannstadt (now Sibiu, Romania) in 1894, Oberth moved to Munich for his medical training, and remained in Germany after the old empire was partitioned in 1918. He spent brief periods of his later life in Austria, Italy, and the United States, but eventually retired to Germany in 1962. He died in 1989, at the age of 95.

Germany's equivalent of Goddard and Tsiolkovskii was without doubt Hermann Oberth. While Goddard had been inspired by Wells, Oberth's interest in space travel was fired by reading Verne's *From the Earth to the Moon* at the age of 11, and within a few years he was making his own model rockets. Though he initially trained to be a doctor at his father's behest, harsh experience as a medic in the trenches of the First World War prompted him to follow his interest in physics. However, he failed to gain a doctorate from the University of Heidelberg, largely because his dissertation explored physiological and medical aspects of rocket travel in which his physicist supervisor had no grounding. Rather than revise and resubmit, Oberth instead financed its publication as a book, *The Rocket into Interplanetary Space* (1923). Just as had happened with Goddard in America, his public promotion of such apparently outlandish ideas soon turned Oberth into something of a celebrity. However, while Goddard was openly mocked for his comparatively modest suggestions, Oberth's far more visionary proposals were welcomed with open arms, partly thanks to bestselling popularizations of the work by authors such as Max Valier and Willy Ley. Even though Oberth had certainly developed most of his ideas, such as liquid-fuelled rockets and multiple stages, independently of either Goddard or Tsiolkovskii, the fact that he had written to the isolated American in 1920 to request a copy of his early papers was enough to arouse some suspicion and envy across the Atlantic – for the rest of his life, Goddard referred to Oberth as "that German".

Throughout the 1920s, Oberth's fame and popularity increased, and in 1929 he published a revised and expanded version of his work, *Ways to Spaceflight*, that attracted even more attention.

OBERTH'S WORK
Hermann Oberth's book The Rocket into Interplanetary Space *(above) inspired engineers such as the members of the VfR. In this photograph (right), Oberth, in the dark overalls, is standing by the rocket intended for launch at the premiere of* Frau im Mond.

ROCKETS AND CINEMA
Frau im Mond *was only a moderate success at the cinema – largely because it was silent at a time when "talkies" were becoming increasingly popular. Ironically, this silent movie can claim credit for inventing the launch countdown, added to the script by Fritz Lang in order to increase tension.*



FRITZ LANG'S VISION
Lang's lunar voyage is a tale of jealousy and mistrust among the crew of an expedition visiting the Moon in search of gold discovered by the astronomer Professor Manfeldt.

IMAGINARY JOURNEY
Although it offered the first realistic depiction of spaceflight, Lang's film was not the first to touch on the idea of a trip to the Moon – that honour goes to French pioneer Georges Méliès's rather more light-hearted Le Voyage dans la Lune *of 1902 (right).*

"the rockets ... can be built **so** ... **powerfully** ... that they could be **capable of carrying a man** aloft."

Hermann Oberth, 1923

Rockets, society, and rocket societies

Why was battle-scarred Germany so open to the opportunities of the rocket when the victorious and more prosperous United States was not? In reality it was just another aspect of the scientific and cultural blossoming that briefly occurred under the Weimar Republic in the 1920s, freed from the repressive conservatism of the old kaiser. The German expressionist films of the time were another, and, not surprisingly, the two eventually came together.

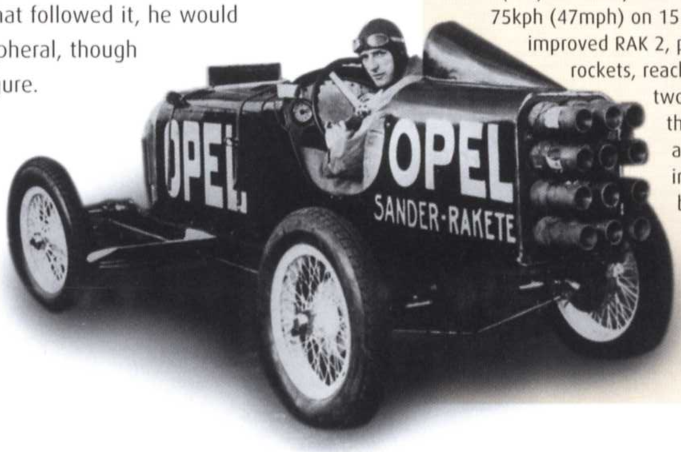
In 1929 the film director Fritz Lang recruited Oberth and Willy Ley to act as consultants for his ambitious new project *Frau im Mond* (The Woman in the Moon), which was to be the first serious film about space travel. The film borrowed heavily from Oberth's ideas and popularized an image of the rocket that has persisted to this day. It also proved that while Oberth was a fine theorist, he was no engineer: persuaded by Lang that a rocket launch would be the perfect publicity stunt to open the film, Oberth and his colleagues laboured for months to build Germany's first liquid-fuelled rocket, but they met with little success, and an explosion during testing cost Oberth the sight in one eye.

Nevertheless, later in 1929 Oberth did manage to test-fire a liquid-fuelled rocket engine called *Kegeldüse* in the laboratory. By this time, he had begun to collaborate with a young and enthusiastic engineer called Wernher von Braun. The two had met through the VfR space and rocketry society (see p.22). Now back on familiar territory as a theoretician and the elder statesman for a new generation of rocketeers, Oberth was finally able to see some of his dreams become reality, as the VfR made a series of successful rocket launches. Throughout the later development of the German missile programme, and the US space programme that followed it, he would remain a peripheral, though influential, figure.

HISTORY FOCUS

ROCKET CARS

Another manifestation of the German obsession with rockets were the rocket-propelled vehicles of the late 1920s. Developed by manufacturing magnate Fritz von Opel in collaboration with powder-rocket maker Friedrich Wilhelm Sander and Austrian space enthusiast and author Max Valier, the Opel-RAK series of cars, aircraft, and even railway carriages began with the RAK 1 (left) driven by Kurt Volkhart to a top speed of 75kph (47mph) on 15 March 1928. The much-improved RAK 2, powered by 24 separate rockets, reached 230kph (143mph) just two months later. Although they were mainly intended as publicity stunts, Valier in particular seems to have been keen to develop the idea further. Tragically, he was killed by shrapnel when the liquid-fuelled engine he planned to fit on the RAK 7 car exploded in his laboratory.



Rocket societies

The 1920s and 1930s saw the formation of a number of rocket societies – clubs where like-minded physicists and engineers collaborated to develop new and more powerful types of rocket.

Most of the world's early rocket societies started out as groups of keen amateur enthusiasts, such as the American and British Interplanetary Societies (established in 1930 and 1933), and the astronautical section of the French Astronomical Society (established in 1927, and for which the term astronautics was first coined). But two in particular caught the attention of their respective governments.

The VfR

Germany's *Verein für Raumschiffahrt* or VfR (Society for Space Travel) was founded in 1927 at Breslaw (now Wroclaw in Poland) by Johannes Winkler, an engineer at aircraft manufacturer Junkers. The authors Max Valier and Willy Ley were early members, and numbers soon swelled to 500 people, including influential figures such as Hermann Oberth, Eugen Sänger, Arthur Rudolph, and a young student called Wernher von Braun.

By February 1931, Winkler was able to launch Europe's first liquid-fuelled rocket, the HW-1, from Dressau. He used a powerful combination of liquid methane and liquid oxygen in his rocket, which was able to reach altitudes of 500m (1,600ft). Over the following months, VfR members conducted a series of increasingly ambitious launches from their rocket airfield near Berlin, using a design conceived by

GIRD 09
Yefremov's early rocket design used liquid oxygen to burn a petroleum gel fuel. This hybrid design achieved far better performance than the GIRD-X. The first launch reached 400m (1,300ft), and later ones reached 1,500m (5,000ft).

YOUNG ENTHUSIAST
The young Wernher von Braun (right) carries an HW-series rocket at the VfR's Raketenflugplatz *(rocket airfield) outside Berlin.*

LAUNCHING GIRD 09
Nikolai Yefremov contends with a dangerous leak of liquid oxygen during one of GIRD's several attempts to launch its hybrid-fuel rocket in August 1933.

GERMAN ROCKETEERS
VfR members including Rudolf Nebel (far left), Hermann Oberth (centre), Klaus Riedel (right of centre in light coat), and Wernher von Braun (far right) are seen here with Oberth's Frau im Mond *rocket. Riedel is holding a Mirak rocket.*

Rudolf Nebel and built by Klaus Riedel. These Mirak rockets were soon able to reach altitudes of more than 1km (⅔ mile).

In 1932, the VfR invited Captain Walter Dornberger of the German Army to view a demonstration. The test launch ended in failure, but Dornberger was sufficiently impressed to offer the group funding – if they would keep their work secret and concentrate on military applications. The Army was particularly interested in rocket weapons because their development was one of the few areas not strictly regulated under the Treaty of Versailles. The VfR eventually turned down Dornberger's offer, but fierce arguments about whether or not to accept it nearly tore them apart. Within a year, the Nazi Party had seized power, and one of their early measures was to outlaw civilian rocket experiments. Von Braun and several other VfR members were soon lured to work for the Army under Dornberger, while many of the others retreated from practical research back into the realms of theory.

GIRD MEMBERS
Proud Soviet space enthusiasts surround their GIRD-X liquid-fuelled rocket prior to its launch in November 1933. A young Sergei Korolev is standing to the right of the rocket.

GIRD

In the Soviet Union, the VfR's equivalent was the Group for the Study of Reactive Motion (GIRD), founded from the merger of two earlier rocket clubs in 1931. It had many local branches, but the most important were those in Moscow and Leningrad (MosGIRD and LenGIRD respectively). MosGIRD was largely instigated by Friedrich Tsander, an enthusiastic advocate of spaceflight. Many of its members were to play influential roles in the Soviet space program, most importantly Sergei Korolev and Mikhail Tikhonravov. LenGIRD, meanwhile, included Valentin Glushko among its members.

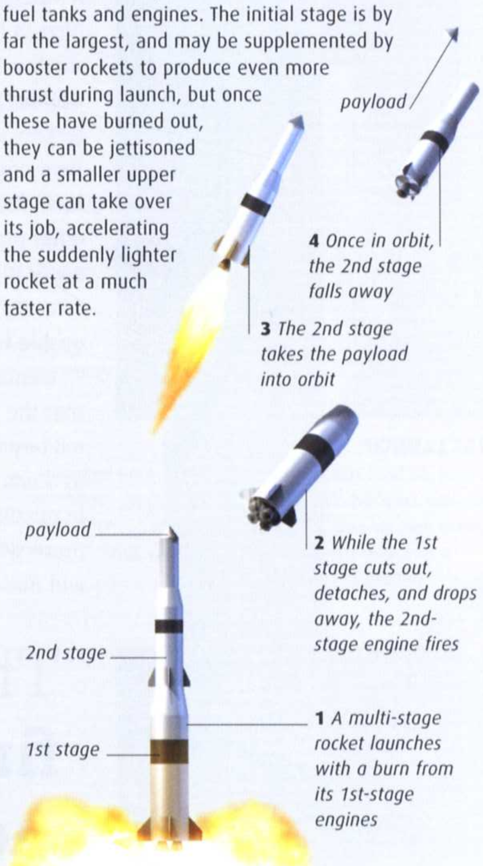
By August 1933, MosGIRD had launched the GIRD 09, based on a hybrid semi-solid rocket engine (which combined fuel and an oxidizer to produce combustion gases and thrust) designed by Tikhonravov and Nikolai Yefremov. In November of that year, the Soviet Union's first true liquid-fuelled rocket, Tsander's GIRD-X, took flight to a height of 80m (250ft), powered by alcohol and liquid oxygen. Tsander, however, did not live to see it – he had died that March from typhus, with Korolev taking his place as GIRD's nominal leader.

While the VfR was an independent civilian group, GIRD never had the same degree of autonomy because most of its members were already working for the Soviet state on rocket-related research projects. As GIRD's activities drew increasing attention from the state, the organization was absorbed into the Red Army under Field Marshal Tukachevsky. Here it was merged with the Gas Dynamics Laboratory (GDL) of Leningrad, creating the Jet Propulsion Research Institute (RNII). The RNII was an organization riven with factional infighting: former GIRD members were frequently in conflict with each other and ex-GDL staff. The RNII's director was more concerned with jet propulsion than with rocketry, and Glushko had work on liquid-oxygen rockets cancelled in favour of his own nitric acid systems. When the paranoid Stalin turned on Tukachevsky at the beginning of the Great Purges of 1937–38, the consequences for the former GIRD members would prove terrible.

TECHNOLOGY

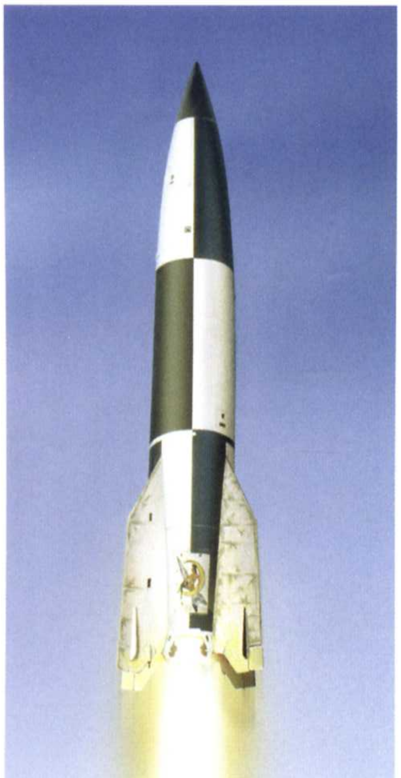
PRINCIPLES OF ROCKET STAGING

All the early rocket pioneers soon hit upon the idea of multi-stage rockets (which Tsiolkovskii called rocket trains). The major problem faced by any rocket is the sheer weight of fuel that it must carry if it is to generate sufficient thrust at launch to get moving against Earth's gravity. As the rocket picks up speed and starts to burn down the fuel supply, it makes no sense to carry the huge volume and weight of a mostly empty fuel tank along for the ride. Instead, it's simpler to split the rocket into separate elements, each with its own fuel tanks and engines. The initial stage is by far the largest, and may be supplemented by booster rockets to produce even more thrust during launch, but once these have burned out, they can be jettisoned and a smaller upper stage can take over its job, accelerating the suddenly lighter rocket at a much faster rate.



The birth of the missile

At first, Walter Dornberger struggled to convince the German Army that rockets could be a practical weapon. But with a rocket team assembled from the cream of the VfR, he would ultimately build the first missiles.



FIRST LAUNCH
The first A4 was ready for launch on 13 June 1942, but crashed due to a guidance failure, as did a second test in August. Finally on 3 October, the third test flight flew for 192km (119 miles).

The VfR chose the right man when they approached Walter Dornberger about potential funding in 1932. A veteran of the First World War who had studied physics for several years, he was in charge of a small weapons-testing facility at West Kummersdorf. Dornberger was a strong advocate of the idea that rockets could be used as ballistic missiles – burning their engines to the peak of their flight path, and then descending on a trajectory similar to that of any other projectile. The first person to suggest such an application had been French rocket enthusiast Robert Esnault-Pelterie in the late 1920s, but he had been unable to interest the French military in the proposal.

Wernher von Braun was among those who argued that the VfR should accept funding to work on military applications. The society's members were as a whole far more interested in spaceflight than in missiles, but there were sharp divisions between those who wanted nothing to do with warfare and those who saw military funding as a means to finally get some serious support for their work. While the VfR ultimately rejected the Army offer, it was inevitable that some of its leading lights would follow the money.

The fruits of their effort were a number of increasingly ambitious rocket designs, the A-series. While the A1 never got off the drawing board let alone the launch pad, von Braun himself was able to launch a pair of A2 rockets, christened Max and Moritz, from the island of Borkum in December 1934. These rockets burned an ethyl alcohol/liquid oxygen propellant mix, and incorporated an important new feature – a spinning gyroscope in their mid-sections. The weight of this spinning mass helped to stabilize the entire rocket, ensuring it maintained a steady flightpath that reached a peak at around 2,000m (6,600ft).

BALTIC HIDEAWAY
The peninsula of Peenemünde, on Germany's northeastern coast, was suggested by Wernher von Braun's mother when he mentioned the need for an isolated site.

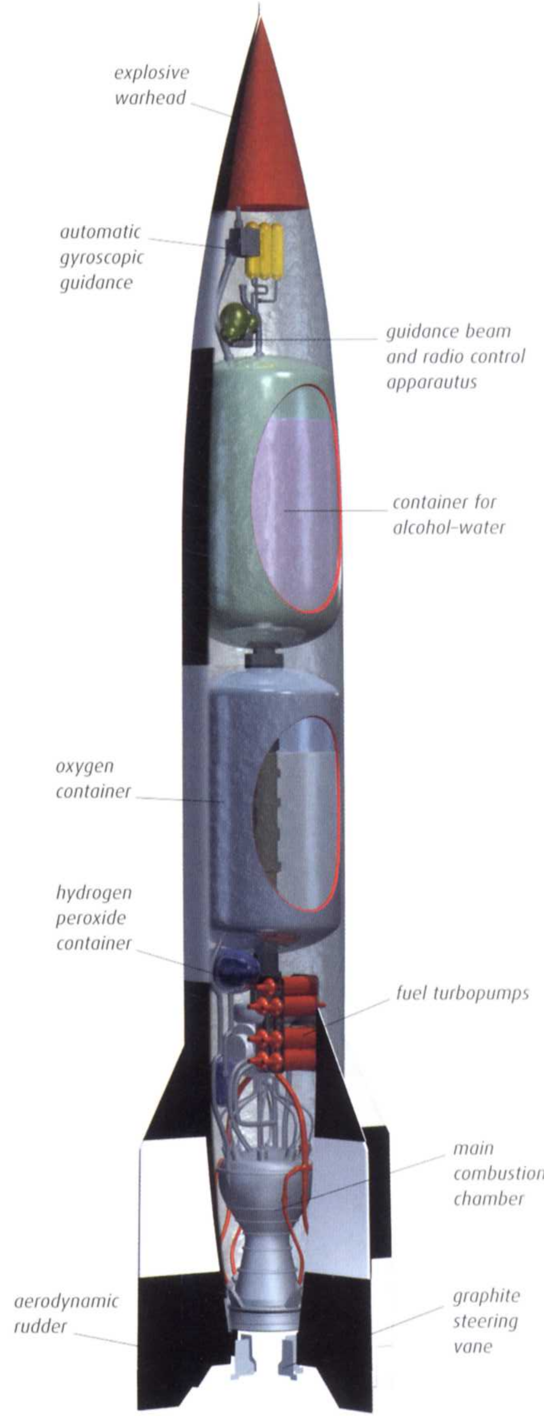
> "This ... is **the first day of a new era** ... that of space travel."
>
> **Walter Dornberger, on the first successful A4 launch, 3 October 1942**

TEST STAND
Preparations for a test at Peenemünde reveal the true scale of history's first large rocket.

HIGH-LEVEL VISIT
The rocket team frequently welcomed high-ranking visitors to Peenemünde (though Hitler visited them only once at Kummersdorf, and seemed unimpressed). Here, Admiral Dönitz and his entourage are seen during an inspection in May 1943. Wernher von Braun is on the right, wearing a dark civllian suit.

This success, and the development of static test engines with far greater power than the A2's motors, convinced the Army to put more money into rockets. As von Braun's team outgrew Kummersdorf, a new base was established at Peenemünde on the Baltic coast. Over the next few years, it would grow to incorporate test ranges, test stands for measuring engine performance, and factories for rocket assembly.

LENGTH	14m (46ft)
MAXIMUM DIAMETER	1.7m (66in)
TOTAL MASS	12,870kgf (28,373lbf)
UNFUELLED MASS	4,008kg (8,836lb)
ENGINES	1 x A4
LIFT-OFF THRUST	25,000kg (55,125lb)
MANUFACTURER	Mittelwerk



THE FIRST MISSILE
The A4 is the ancestor of all other liquid-fuelled rockets, including most modern ballistic missiles and space launch vehicles. To this day, rocket technology still follows the same principles set out by the A4 team.

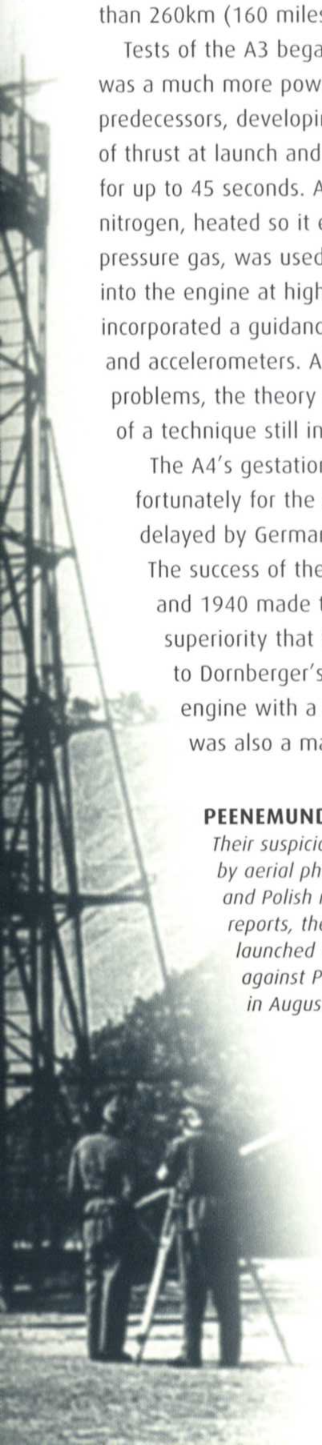
Building the A4

By the summer of 1936, Nazi Germany was preparing for war. A new test rocket, the A3, was in development, but the pressure to produce a practical missile for warfare was growing. The result was an outline for the A4, a massive rocket that would scale up all their existing systems. Dornberger suggested that it should be able to carry a 100-kg (220-lb) explosive warhead over more than 260km (160 miles).

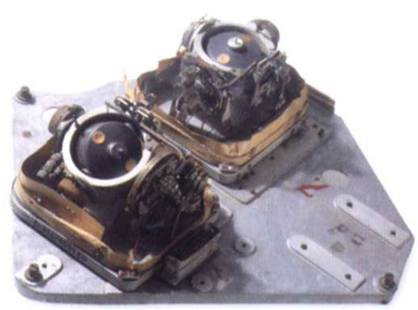
TESTING KIT
This box of electronics was used for pre-launch tests on A4 rockets. Generally the launch sequence was triggered from inside an armoured vehicle or blockhouse close to the launch site, with all other personnel kept back at a safe distance.

Tests of the A3 began in late 1937. This was a much more powerful rocket than its predecessors, developing 1,500kg (3,300lb) of thrust at launch and capable of burning for up to 45 seconds. A small tank of liquid nitrogen, heated so it evaporated into high-pressure gas, was used to force propellant into the engine at high speed. The A3 also incorporated a guidance system of gyroscopes and accelerometers. Although this had practical problems, the theory was sound – the first use of a technique still in use today.

The A4's gestation was a long one – and fortunately for the Allies, its debut was partly delayed by Germany's own military hierarchy. The success of the Blitzkrieg attacks of 1939 and 1940 made the Army so convinced of its superiority that it opted to cut back on funding to Dornberger's project. But building an engine with a thrust of 25,000kg (55,125lb) was also a massive technical challenge. The main problem for the scientists was how to force fuel into the combustion chamber at a fast enough rate to produce the required thrust. The solution was a high-speed turbopump, powered by the fierce chemical reaction of hydrogen peroxide and potassium permanganate. In the meantime, other systems were tested on a new research rocket, called the A5. By the time the first A4 successfully launched, on 3 October 1942, Germany's hopes for a swift war had been dashed and much was expected of the new weapon. This was soon to have a new name.



PEENEMUNDE RAID
Their suspicions aroused by aerial photographs and Polish resistance reports, the Allies launched air raids against Peenemünde in August 1943.



GUIDANCE GYROSCOPES
The later A-series rockets used several gyroscopes and accelerometers to calculate the rocket's precise trajectory, speed, and distance travelled, so that it could be guided using steering vanes that deflected the exhaust.

The missile goes to war

Although the first successful A4 launches occurred in late 1942, it took almost two more years before the missile was ready to enter service. By that time, it had acquired a more infamous pseudonym – the V-2.

MOBILE LAUNCHER
One reason for delays to the V-2 entering service was the need to develop a transport system for it. The rockets had to be fuelled and transported from Nordhausen to forward units via the rail network before they came within range of the enemy cities.

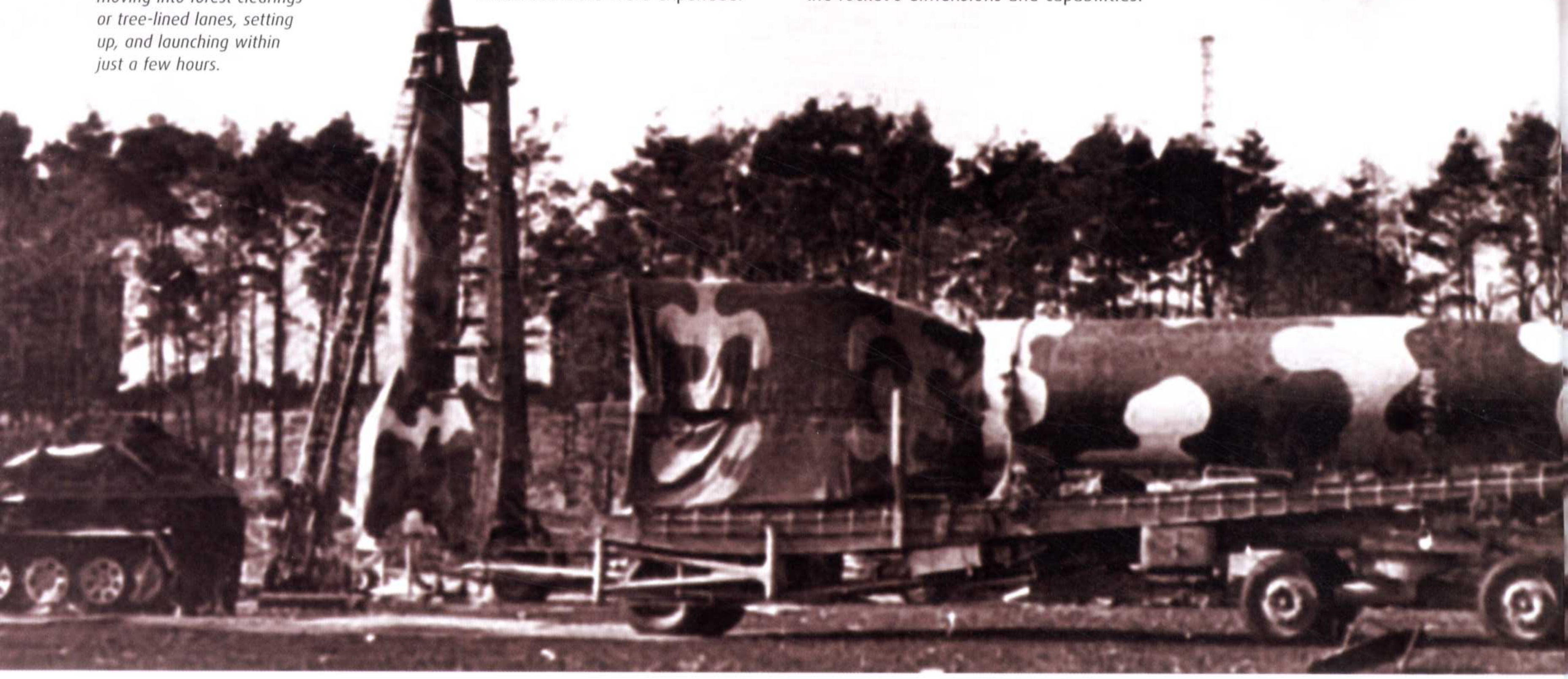
HIT AND RUN
A standard V-2 battery would consist of about 30 vehicles – Meillerwagens, *mobile generators, fire trucks, tow trucks, and troop transporters. They became proficient at moving into forest clearings or tree-lined lanes, setting up, and launching within just a few hours.*

As the A4 edged closer to mass production, it was increasingly clear that Peenemünde was not well-suited to large-scale manufacturing or perhaps even continued testing. The devastating Allied raids of August 1943 proved the final straw – among the casualties was Walter Thiel, the ingenious designer of the A4's high-performance engine. The decision was made to move much of the flight testing to Blizna in southern Poland, while large-scale manufacture of the missiles would begin in the huge Mittelwerk tunnel complex under the Kohnstein mountain near the town of Nordhausen in central Germany. The main focus of those remaining at Peenemünde would be research and development.

At the insistence of Joseph Goebbels's propaganda ministry, the A4 was henceforth to be called the Vergeltungswaffe-2 (Reprisal Weapon 2), or V-2 for short. The name V-1 had been given to the Luftwaffe's jet-propelled "flying bomb", tested alongside the V-2 at Peenemünde and also manufactured at the Mittelwerk. To provide a slave workforce for the huge underground factories, concentration camps at nearby Mittelbau-Dora were expanded. By the end of 1943, thousands of prisoners were being worked to death in appalling conditions beneath the mountain.

Even with these massive resources, production did not go smoothly – von Braun's team at Peenemünde was still refining the rocket, and every modification resulted in lost time and lost lives among the labourers. Meanwhile, construction of infrastructure for the new weapons was under way. While the V-1 flying bombs required long concrete "ski ramps" to assist their take-off, the V-2 was designed for rapid deployment on mobile launchers. Nevertheless, the German military began planning a number of bunkers along the French coast that it intended to use for V-2 launches, but the Allied air forces subjected these to such heavy bombing that they were eventually abandoned.

By mid-1944, shortly after the D-day landings that started the liberation of mainland Europe, the Allies had a good idea of what was coming – parts of crashed V-2s had been smuggled to London from both Poland and Sweden, and aerial reconnaissance missions had given intelligence analysts an insight of the rocket's dimensions and capabilities.

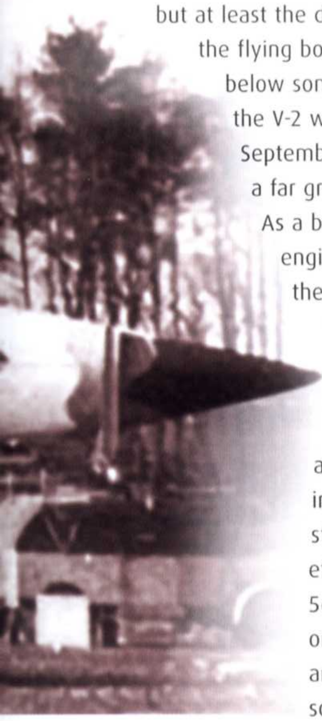


SCENE OF DEVASTATION
When a V-2 struck the corner of Smithfield Market in central London, early on the morning of 8 March 1945, it killed 110 people. However, this was one of the last missiles to reach Britain – within weeks the V-2 launchers had been driven back out of range.

"... they travelled **faster than the speed of sound** ... The first you knew was the explosion."

Eyewitness to a V-2 attack, London, 1944

Terror from the skies



The first V-1s began to fall on London in June 1944, but at least the distinctive engine sound from the flying bombs offered the civilians below some advance warning. When the V-2 was finally deployed in early September, its silent approach had a far greater psychological effect. As a ballistic missile, the V-2's engines only fired until it reached the peak of its trajectory. It then fell almost noiselessly towards its target. The guidance systems were too primitive to make the V-2 anything other than a blunt instrument, but when it did strike a populated area, the effect could be devastating: 567 people were killed when one struck a cinema in Antwerp, and 160 died in a strike on southeast London. The difficulty in targeting meant that most of the missiles were aimed at major cities rather than smaller towns – between them, London and Antwerp endured some 90 per cent of more than 3,000 attacks by the rockets. Each V-2 carried a warhead with more than a tonne of explosives, and its final approach, dropping from an altitude of around 100km (60 miles) at up to four times the speed of sound, left no possibility for interception or defence.

By the time the V-weapons were deployed, though, the German Army was in retreat, and firing them from their *Meillerwagen* launch platforms became a hit-and-run operation. A practised V-2 crew could set up, launch a missile, and depart within two hours – usually moving too quickly for the launcher to be spotted and destroyed on the ground. Ultimately the V-2 attacks were only brought to an end as the German Army was driven into retreat and the target cities fell out of range. The bombardment finally ceased in March 1945.

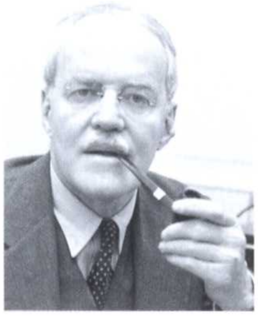
Final attack

More than 6,000 V-2s were produced in total, but they were far from reliable weapons, and early models had a tendency to disintegrate in mid-flight that was not corrected until late 1944. Despite inflicting heavy casualties, the missiles never came close to turning the tide of the war – by the time the V-2 entered service it had truly become the Nazi regime's Reprisal Weapon, a final psychological attack on the Allies at home, even as their armies were sealing Germany's own fate on mainland Europe.

UNDER THE MOUNTAIN
Colour photographs from the Nazi era grimly capture the reality of life and work beneath the mountain at Nordhausen. Up to 10,000 forced labourers worked underground in the factory at its peak, helping to produce not only the V-2, but also the V-1. Many of the workers died of pneumonia in the cold, damp conditions.

The winners take all

The V-2 attacks revealed Germany's massive lead in rocket development, and as wartime alliance turned to Cold-War rivalry, the United States and the Soviet Union were racing to plunder the German rocket programme.



ALLEN DULLES
The US end of Operation Overcast/Paperclip was driven by Allen W. Dulles of US Army Intelligence, later director of the CIA under President Eisenhower.

Although their intervention had come too late to affect the outcome of the war, von Braun's missiles had proved one thing beyond doubt – the rocket was once again a formidable weapon: fast, almost silent on its final approach, and difficult to intercept. Clearly, ballistic missiles would have a major role to play in future warfare, and as the leaders of the democratic West and communist East contemplated a situation in which their rival spheres of influence would clash around the world, getting hold of superior German technology became a high priority.

In February 1945, Captain Robert Staver arrived in Europe under instructions to track down the V-2 masterminds and bring them into US custody. A month later, Colonel Holger Toftoy, head of Army Ordnance Intelligence in Paris, was ordered to track down as many intact V-2s as possible, for later use in a testing programme. For both men, it was a race against time – many of the Germany's key missile sites lay directly in the path of the advancing Red Army. Fortunately for the Americans, though, von Braun and his team had plans of their own.

DORA ARTEFACTS
The Nazis kept paperwork on all aspects of the rocket programme, ranging from construction contracts to special camp banknotes.

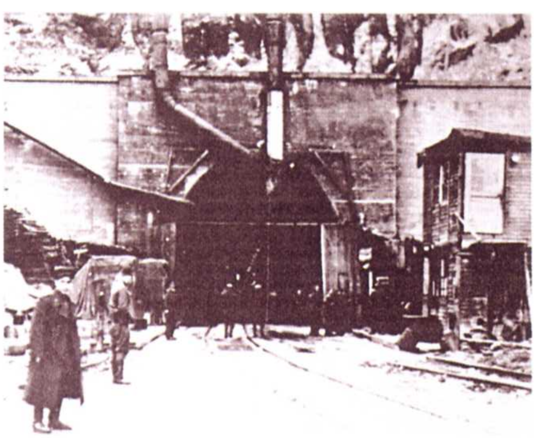
Willing captives

When the Soviet armies swept into Peenemünde on 5 May 1945, they found that the birds had flown – the missile range and factories had been abandoned in mid-February, and explosives deliberately set to destroy as much as possible. Von Braun and his team had moved first to Nordhausen, close to the Mittelwerk factory, and closer to the advancing US troops. On 19 March, orders came from Berlin that all records of German experimental programs were to be destroyed – instead, von Braun had 14 tonnes of material spirited away in the night and hidden in a cave for later recovery.

Since August 1944, the V-2 team had been under the command of SS General Hans Kammler, a former concentration camp commandant who apparently planned to use them to barter for his life. In late March he had the entire team shipped south to Bavaria. During April, Kammler disappeared – perhaps assassinated, perhaps fleeing for his life. When the 44th Infantry Division finally reached the village on 2 May, von Braun and his team were able to surrender to their captors of choice.

The soldiers may not have immediately realised the value of their prize, but Robert Staver certainly did. Nordhausen had been captured on 11 April, with huge stores of missile components, but no sign of the scientists or their paperwork. Another problem was that both Nordhausen and Garmisch-Partenkirchen, where the scientists were being questioned, were due to be handed over to Soviet administration in June. In Paris, Toftoy saw the need to move fast. He despatched a team to Nordhausen to collect the parts for 100 V-2s, and

"TAKE US TO IKE!"
Leaders of the V-2 team after capture in Bavaria. Von Braun had broken his arm in a car crash a few weeks earlier. Dornberger is on the left in the hat.



ENTRANCE TO UNDERGROUND FACTORY
At Kohnstein the US troops discovered a huge complex carved out of the soft gypsum rock. In the early years of the Second World War the complex was used as a store for fuel and poison gas. Most prisoners who died at Mittelwerk had perished in the first few months of heavy labour.

THE PRODUCTION LINE
The assembly lines ran through two parallel tunnels, A and B, each 1.9km (1¼ miles) long. Missiles were placed on carriages and rolled along the railway tracks that connected the many halls in Tunnel B. The final hall, over 15m (50ft) high, allowed missiles to stand vertically for testing.

STORES OF FINISHED PARTS
Tunnel A was used for transporting parts and equipment into and around the factory, while the numerous shorter cross-tunnels were used for storage. The production-line manufacture of the V-2s meant that large stores of completed parts were kept on site.

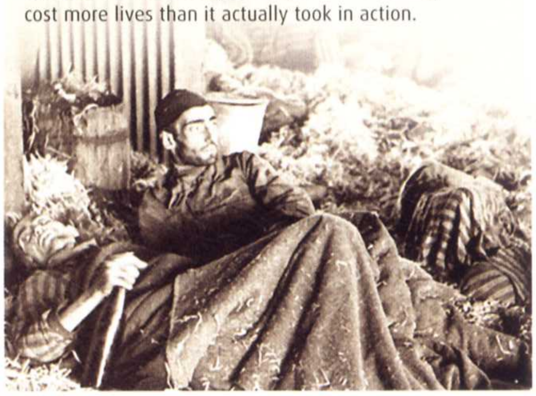
"Germany has lost the war, but let us not forget that it was our team that first succeeded in **reaching outer space** ..."

Wernher von Braun, referring to the V-2 reaching an altitude of 100km (60 miles), 1945

HISTORY FOCUS

MITTELBAU-DORA

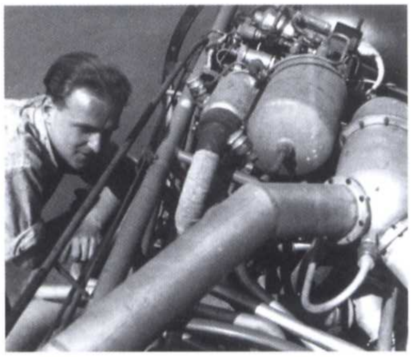
The concentration camps at Mittelbau-Dora were liberated by US forces on 11 April 1945. Conditions here were little better than at other camps, and those who the Nazi state regarded as inferior or criminal were subjected to backbreaking work on starvation rations. When the Mittelwerk V-2 factories were fully operational, they required some 5,000 prisoners. At least 26,500 are thought to have died here during the factory's 20 months of operation – about five lives for each completed missile. It has been rightly pointed out that the V-2 was a unique weapon – the making of it cost more lives than it actually took in action.



ship them back to the US zone. Staver also based himself at Nordhaüsen, where he tracked down a number of senior members of the rocket team that had not gone south and located the hidden cache of documents. As the handover deadline neared, Staver and Toftoy arranged a mass evacuation of Peenemünde staff and their families to the US zone.

On 19 July, Operation Overcast (later Paperclip) was given the go-ahead by Washington. Staver and Toftoy were authorized to offer the Germans six-month contracts for work in the US. Most took some persuading – their families would have to remain behind in Germany – and the future beyond those six months was uncertain. The first contracts were finally signed on 12 September, and within days, the initial wave of scientists was flying out of Europe.

Although most of the rocket team had eluded them, the Soviets still had a large share of the plunder. Peenemünde and Nordhausen were now theirs, and a few key scientists, notably Helmut Gröttrup of the guidance and control team, also cast their lot to the east. On balance, then, the superpowers were fairly evenly matched as they began their post-war missile race.



OPERATION BACKFIRE

In the summer and autumn of 1945, the British Army conducted a number of test firings of V-2s (left) captured during their advance through the low countries. Launches took place at Cuxhaven in northern Germany, and rocket team scientists (above) were frequently flown in from their camp in the south to assist.

Von Braun: model American

The most important figure on the American side of the Space Race was to be a naturalized German whose intimate involvement in the V-2 programme would continue to raise awkward questions even as he became a renowned national figure.

THE V-2 ARRIVES
Captured German rockets were transported to the United States aboard aircraft carriers such as USS Midway, before being transferred to Fort Bliss or direct to White Sands.

THE ROCKET TEAM
This group photo shows 105 of the 116 German rocket experts at White Sands Proving Ground in 1946. Von Braun is in the front row, right of centre, with one hand in his pocket.

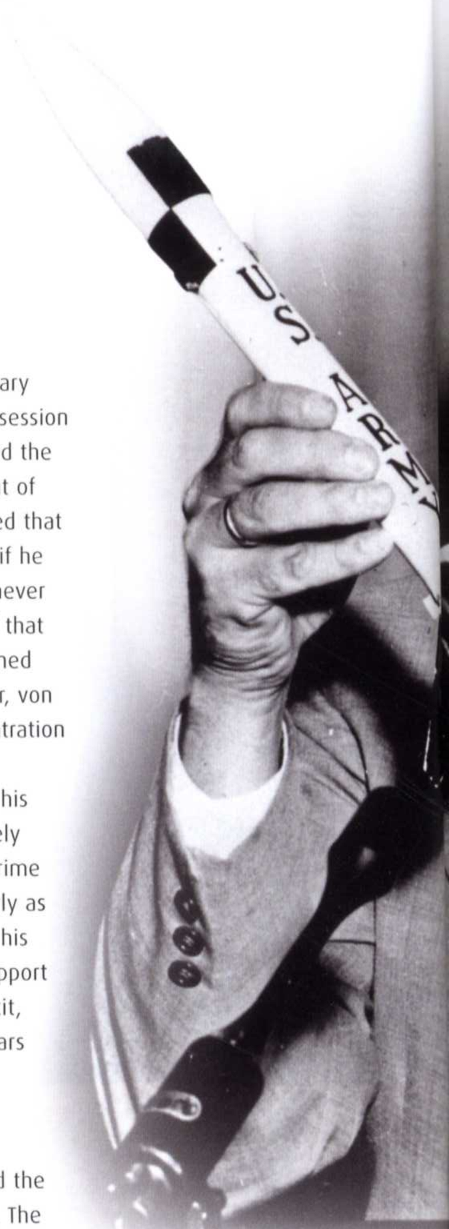
Wernher von Braun arrived at Fort Bliss, Texas, on 29 September 1945, one of an initial group of seven German scientists brought into the United States as part of Operation Overcast. During nearly five months of evaluation in Germany, he had been interviewed by American rocket experts such as Tsien Hsue-Shen, prepared reports for the US Army on the status of the German rocket programme, and helped the Americans round up the rest of his team. If there had ever been any doubt among the US military that von Braun was the man they needed in their new missile programme, his willing cooperation dispelled it.

Von Braun was born in 1912 at Wirsitz in the German province of Posen (now part of Poland), the second son of a noble family. Fascinated by astronomy from an early age, his interest in rockets was fired by reading Hermann Oberth's influential work. At the age of 12, he attempted to imitate the exploits of Wan Hu (see p.12) by strapping rockets to the back of a trolley and piloting it along the Berlin streets. Keen to master Oberth's theories, the young von Braun applied himself to the study of physics and maths, eventually enrolling at the Technical High School of Charlottenburg aged 18. It was here that he joined the VfR and demonstrated his talent for practical rocket engineering.

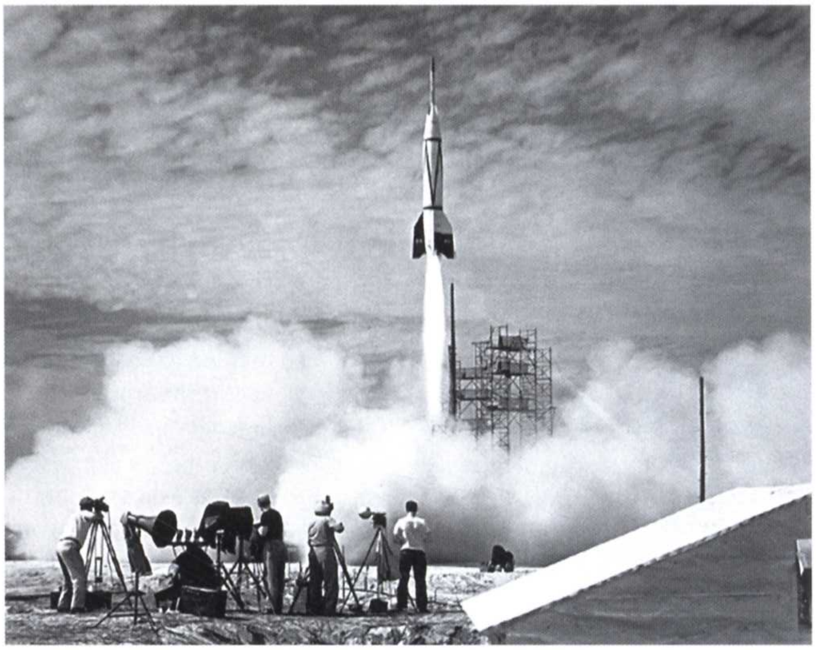
Von Braun's Nazi past was a constant source of controversy throughout his American career – even today it continues to cast a shadow over the early days of the US space programme. It is all but impossible to judge in hindsight, but his primary motivation seems always to have been an obsession with the rocket's use in space travel. He joined the Nazi party in 1937 and was made a lieutenant of the infamous SS in 1940, but he always argued that these were politically necessary manoeuvres if he was to keep working on his rockets; that he never paid more than lip service to Nazi ideals; and that his SS position was purely for show – he claimed only to have worn the uniform once. However, von Braun was certainly well aware of the concentration camps around Mittelwerk and of the foreign forced labour used at Peenemünde. Whether his involvement in a missile programme ultimately launched against civilian targets was a war crime in itself is still a subject for debate, particularly as Dornberger was prosecuted after the war for his role in the project. However, Dornberger's support for the Nazi Party was always far more explicit, and even he was imprisoned for only two years before also travelling to the United States.

The life of Fort Bliss

Throughout 1946, the Americans reassembled the nucleus of von Braun's old team at Fort Bliss. The documentation spirited away from Nordhausen arrived, and dozens of captured missiles and tonnes of parts from the Mittelwerk factories were shipped



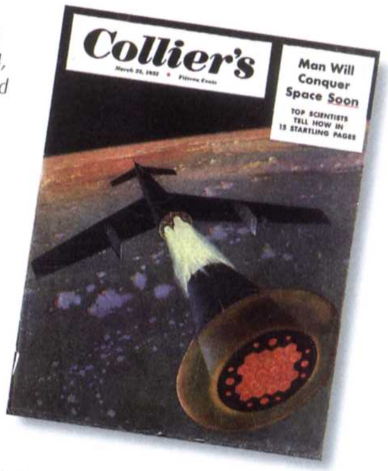
LAUNCHING BUMPER
One of the Fort Bliss team's early projects was Bumper, a basic test of a two-stage rocket design consisting of a small WAC Corporal missile mounted on top of a V-2 first stage. The Bumper launches set a series of altitude records, topping out at 393km (244 miles). These missions, and the White Sands V-2 launches, were among the first to carry scientific instruments to the edge of space.



to America. The chief role for the group was to advise on the reconstruction and test-firing of the captured V-2s at the nearby White Sands range in the New Mexico desert and to help interpret the wealth of paperwork containing the secrets of the German rocket programme. By this time, there was another important factor driving the development of ballistic missiles – the devastating explosions over Japanese cities that had finally ended the Second World War in the Pacific had also heralded a new era of atomic warfare. The Soviets would now be racing to develop their own nuclear weapons, and while the Hiroshima and Nagasaki bombs had been dropped from aircraft, it was clear that if the United States was to maintain its military superiority, the delivery system of choice would be a continent-spanning supersonic missile armed with a nuclear warhead. Indeed, the desire of the superpowers to demonstrate superior missile technology became a key factor during the early decades of the Space Age.

The months spent at Fort Bliss were frustrating ones – work on reconstructing and testing the V-2s was painfully slow, not helped by a slender budget and occasional bureaucratic hold-ups caused, for example, by FBI director J. Edgar Hoover's fears that the rocket team was a security risk. The Germans leapt at any chance for more stimulating activity, such as writing reports and articles, and later devising the flight of scientific instruments and mice and a few small monkeys on board the V-2s.

Von Braun, as ever, was keen to promote the idea of spaceflight, and began to voice his opinions to anyone who would listen – both within the military and, increasingly, in the popular media. And so the American public began its complex relationship with Wernher von Braun – one that would see him pilloried as a closet Nazi in the satirical movie *Dr. Strangelove*, yet fêted as the genius who ultimately put Americans on the Moon.



COLLIER'S MAGAZINE
Between 1952 and 1954, von Braun, Willy Ley, and Hans Haber (an expert on the effects of space travel on the human body) explained their vision for the future of space exploration in the pages of Collier's *magazine.*

ROCKET SALESMAN
Von Braun soon proved himself as influential an advocate of rocketry and space exploration in the media as he was within the corridors of power. Here, he brandishes a model of the Redstone rocket at a press conference. In the 1950s, he would cement his place in the American public consciousness by collaborating with Walt Disney on a series of popular television documentaries.

HISTORY FOCUS

LEGALIZING THE ROCKET TEAM

As the Germans were joined by their families and became settled in America, Operation Paperclip faced a bureaucratic dilemma. Since the rocket team had been flown directly into the United States without visas, it was impossible to officially acknowledge their presence in the country. The eventual solution was somewhat farcical – the Germans were driven in buses across the Mexican border to the town of Juárez, where they applied for US entry visas before being readmitted to the country. It wasn't until 1955, however, that many took citizenship at a ceremony in Huntsville (below).

The Chief Designer

While Wernher von Braun soon became a familiar figure in the US media, his main rival carried out his greatest work beneath a cloak of anonymity. Sergei Pavlovich Korolev, known as the Chief Designer of Spacecraft, was a talented engineer who gave the Soviet Union a lead in space which it maintained until his death.

YOUNG KOROLEV
Korolev's passion for aviation was supposedly triggered by watching an air display as a boy in 1913. Up to and during the Second World War, his principal work was on aircraft designs.

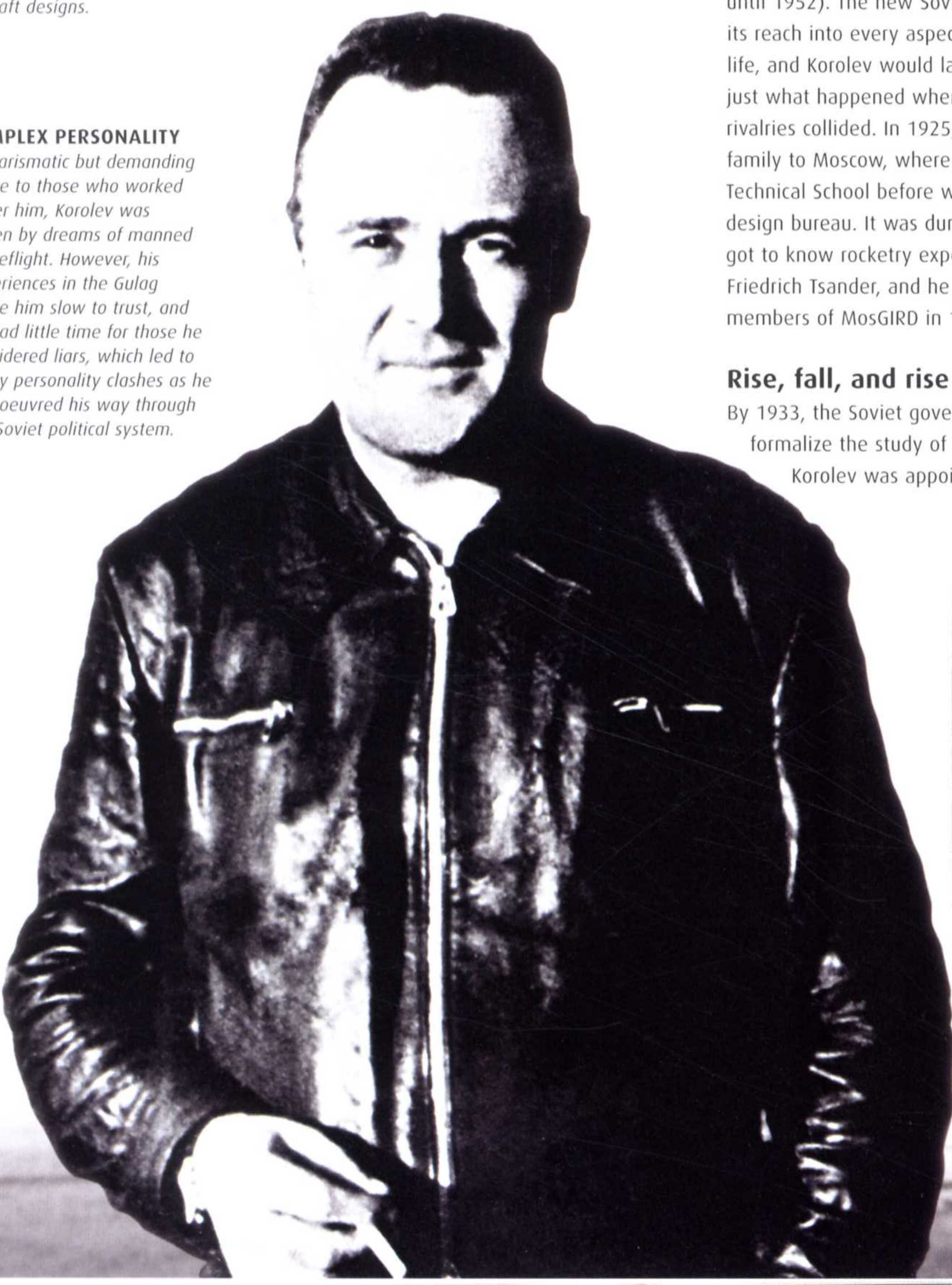
The contrast between the two men who would ultimately drive opposing sides in the Space Race could be traced back to their birth. Von Braun was a scion of German nobility, Korolev the son of a poor craftsman, born in Zhytomyr, Ukraine, in 1907. His parents separated when he was three, though his mother told the young boy that his father had died. Raised largely by his grandparents, Korolev proved himself a good student with a head for mathematics. When his mother married an electrical engineer in 1916, his new stepfather introduced him to practical engineering. Shortly afterwards, on the eve of the Russian Revolution, the family moved to Odessa, where Korolev pursued a growing interest in aircraft.

In 1923, he joined a local Ukrainian aviation society, where he gained first-hand flying experience and was also subjected to communist indoctrination (though he would not join the Communist Party until 1952). The new Soviet government extended its reach into every aspect of public and private life, and Korolev would later learn to his cost just what happened when personal and political rivalries collided. In 1925, he moved with his family to Moscow, where he studied at the Bauman Technical School before working in an aviation design bureau. It was during this period that he got to know rocketry expert and space enthusiast Friedrich Tsander, and he became one of the founder members of MosGIRD in 1931 (see p.23).

RESEARCH ROCKET
An elegant Soviet R-2 awaits launch on the test range at Kasputin Yar in southern Russia. Derived from an undeveloped German modification of the V-2, it first flew in 1950. The R-2 was longer and slimmer than the V-2/R-1 design, had a more powerful engine, and incorporated two pods along its hull, which could carry scientific instruments and animal passengers to high altitudes.

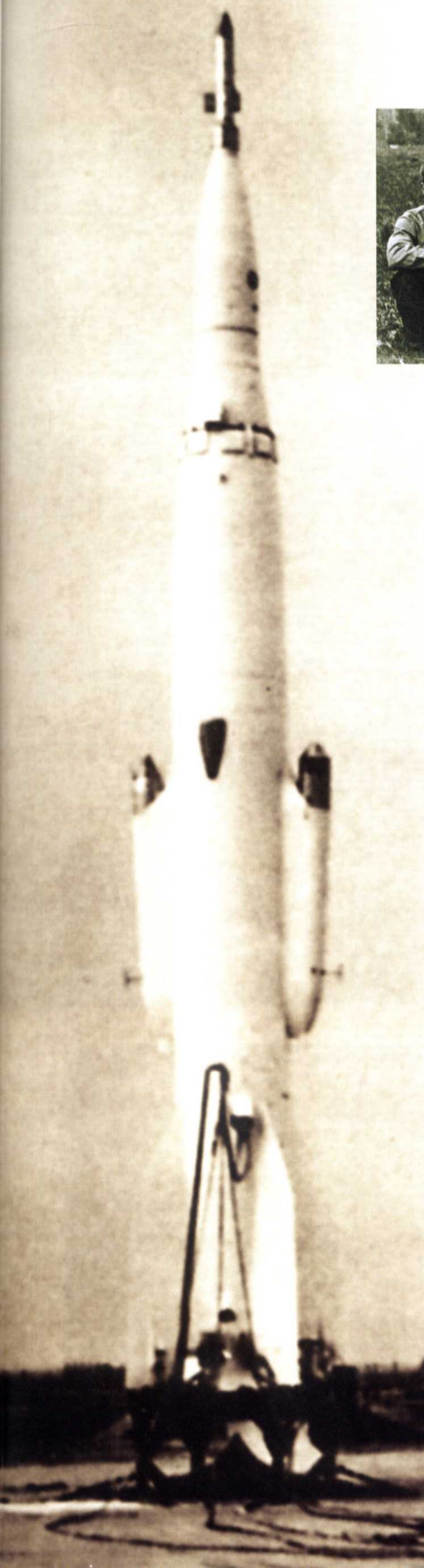
Rise, fall, and rise

By 1933, the Soviet government had decided to formalize the study of rocket propulsion, and Korolev was appointed Deputy Chief of the



COMPLEX PERSONALITY
A charismatic but demanding figure to those who worked under him, Korolev was driven by dreams of manned spaceflight. However, his experiences in the Gulag made him slow to trust, and he had little time for those he considered liars, which led to many personality clashes as he manoeuvred his way through the Soviet political system.

YOUNG DAREDEVIL
In 1929, Korolev (left) and Savva Lyushin (centre) designed a rocket-powered glider, the SK-9, which Korolev copiloted from Moscow to Koktebel in the Ukraine. Here, the famous pilot K.K. Artseulov (right) inspects the glider.



AVIATION SCHOOL
Korolev (second left) is seen here during his time at Moscow's Bauman Technical School, where one of his advisers was the aircraft designer Andrei Tupolev.

new Jet Propulsion Research Institute (RNII), working on the development of missiles and rocket-powered aircraft. It was here that he first met Valentin Glushko (see panel, right), who was to be a lifelong rival. The 1930s saw the peak of Soviet leader Joseph Stalin's reign of terror, and in 1937–38 a wave of purges of suspected saboteurs, spies, and traitors swept through the country. Many people seized the chance to advance their careers or settle old scores by informing on anything that could be seen as remotely subversive, and Korolev's iconoclastic personality made him a target. The knock on the door came on 22 June 1938. Only later did Korolev learn that Glushko had been his chief accuser.

At first Korolev was sent to the harsh environment of a Siberian Gulag, but with the outbreak of the war expertise like his was too valuable to waste, even in a paranoid society like Stalin's Russia. By 1942, he was working in a specialist Moscow prison for scientists, ironically under Glushko's leadership. Here Korolev worked on rocket-assisted fighter aircraft. His loyalty to the Soviet Union duly demonstrated, he was finally released in June 1944 (though he would wait until 1957 for a pardon).

BIOGRAPHY

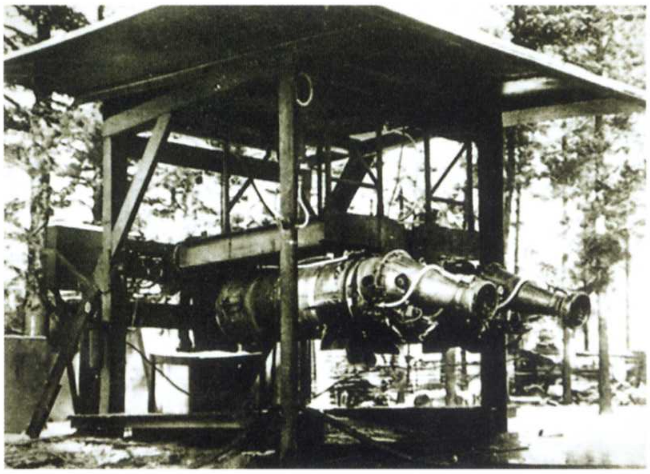
VALENTIN GLUSHKO

Ukrainian-born like Korolev, Valentin Petrovich Glushko (1908–89) developed a complex rivalry with his colleague, which saw them forced to work together throughout the heyday of the Space Race. His enthusiasm for space travel fired by reading the novels of Jules Verne as a boy, Glushko studied physics at Leningrad (modern St. Petersburg), working at the Gas Dynamics Laboratory (GDL) and joining the Leningrad branch of GIRD in 1931. The merger between GIRD and the GDL first brought him into contact and conflict with Korolev, as they worked together for the RNII. Glushko was arrested during the purges of 1938, and seemingly turned informant under intense pressure. In 1946, he was made Chief Designer of OKB 456, in charge of rocket engine development.

Within months, Korolev found himself commissioned as a colonel in the Red Army and flown to Soviet-zone Germany to work under General Lev Gaidukov on the recovery and reconstruction of V-2 related material. One story recounts how he and another officer attempted to gatecrash a British Operation Backfire launch at Cuxhaven, only to be reduced to watching from outside the perimeter fence.

Returning to Russia, Korolev was put in charge of a design team at Scientific Research Institute 88 (NII-88). The institute's main role was to develop ballistic missiles, but the post allowed him to work on technology that could later be used for space travel. Early programmes involved replication of the German V-2 (called the R-1) and improvements in the form of the R-2 and R-3. However, the limitations of V-2-based designs were becoming clear, and Korolev had ambitious plans for the future.

TESTS AT GORODOMLYA
A number of German V-2 scientists working for the Soviet Union, led by Helmut Gröttrup, were transported to Russia in 1946 and mostly settled on Gorodomlya Island, north of Moscow. Here they worked on various projects for Korolev and others. Engine test stands, wind tunnels, and other equipment were shipped in, but the main role of the Germans was to train a new generation of Soviet rocket scientists.

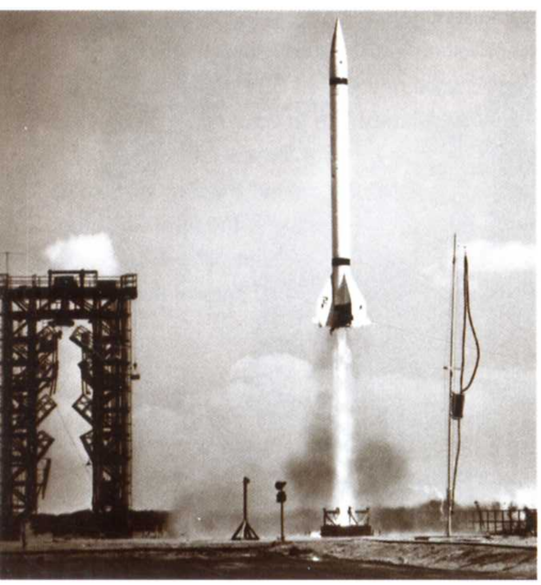


Missiles and rocket planes

The late 1940s saw a missile race in which both the United States and the Soviet Union strove to develop more powerful and longer-range missiles, and even experimental planes, from captured German technology.

X-1 ROCKET PLANE
Bell Aircraft's rocket-propelled X-1 was the first aircraft to travel through the sound barrier and to near the edge of space (see panel, below, and over).

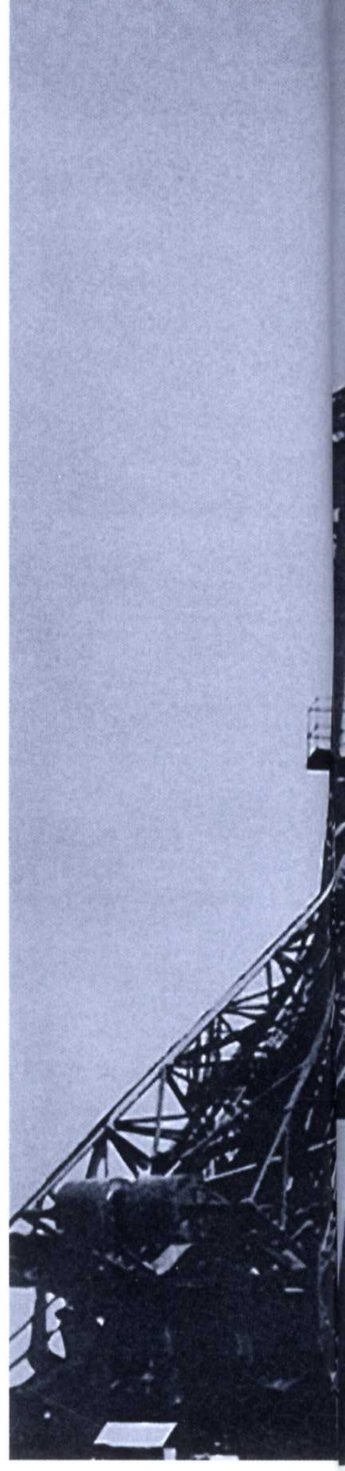
In early 1950, the German rocket team at Fort Bliss began its relocation to Huntsville, Alabama, where wartime munitions factories were to be transformed into a new centre for the development and manufacturing of long-range ballistic missiles. A project called Hermes-C1, previously under slow development at General Electric, was reassigned to the new base at Redstone Arsenal. The intention was that the new missile, later known simply as the Redstone, should be capable of delivering a nuclear warhead over 320km (200 miles). Although the warhead was much heavier than that carried by the V-2, the range was similar and the Germans saw little challenge in the task. They effectively re-engineered the V-2 with a range of improvements, some of which had first been suggested back at Peenemünde. By mid-1953, the first Redstones were being launched from a little-known test range at Cape Canaveral, Florida. Elsewhere in the United States, other groups were also developing new applications of rocket technology. The Jet Propulsion Laboratory (JPL), part of the California Institute of Technology, was working on short-range tactical missiles, often powered by solid propellants much more energetic than black powder. The Navy was developing a series of research rockets called Viking, capable of carrying cameras and experimental payloads high into the atmosphere. And the National Advisory Council on Aeronautics (NACA) was working on a variety of bizarre experimental ideas, often drawing on schemes developed in Germany during the last years of the Second World War. These ultimately became the first X-planes, prototypes that tested technologies which later became commonplace. The first of these strange aircraft was the Bell X-1, a highly successful rocket-propelled plane (see panel, right, and over).



NAVAL RIVAL
Von Braun's team were not the only branch of the US military working on rocket development. The US Navy had its own programme, Viking, under development, though these were sounding rockets intended for scientific purposes.

The Soviet programme continued to be led by Korolev. In his role at NII-88, and from 1946 as Chief Designer at the head of his own experimental design bureau, OKB-1, he was the driving force behind the Soviet Long-Range Ballistic Missile (LRBM) programme. The first fruits of this project were derived from German technology – the R-1 missile, which entered service in 1950, was a more or less direct copy of the V-2, and the R-2, with its extended range and payload, still copied essential elements. However, the next major missile project, the R-3, required a huge leap in capability and a completely new missile design. Korolev established an informal Council of Chief Designers, at which the heads of the six OKB bureaus would meet and collaborate on ambitious projects such as this. Valentin Glushko in particular played a crucial part – he led the design team at OKB-456, working on more powerful and reliable liquid-fuelled engines.

Many of Korolev's early experiments had involved solid-fuel rockets, but his experience with the captured V-2s brought him to the realization that liquid fuel was the key to long-range missiles. The

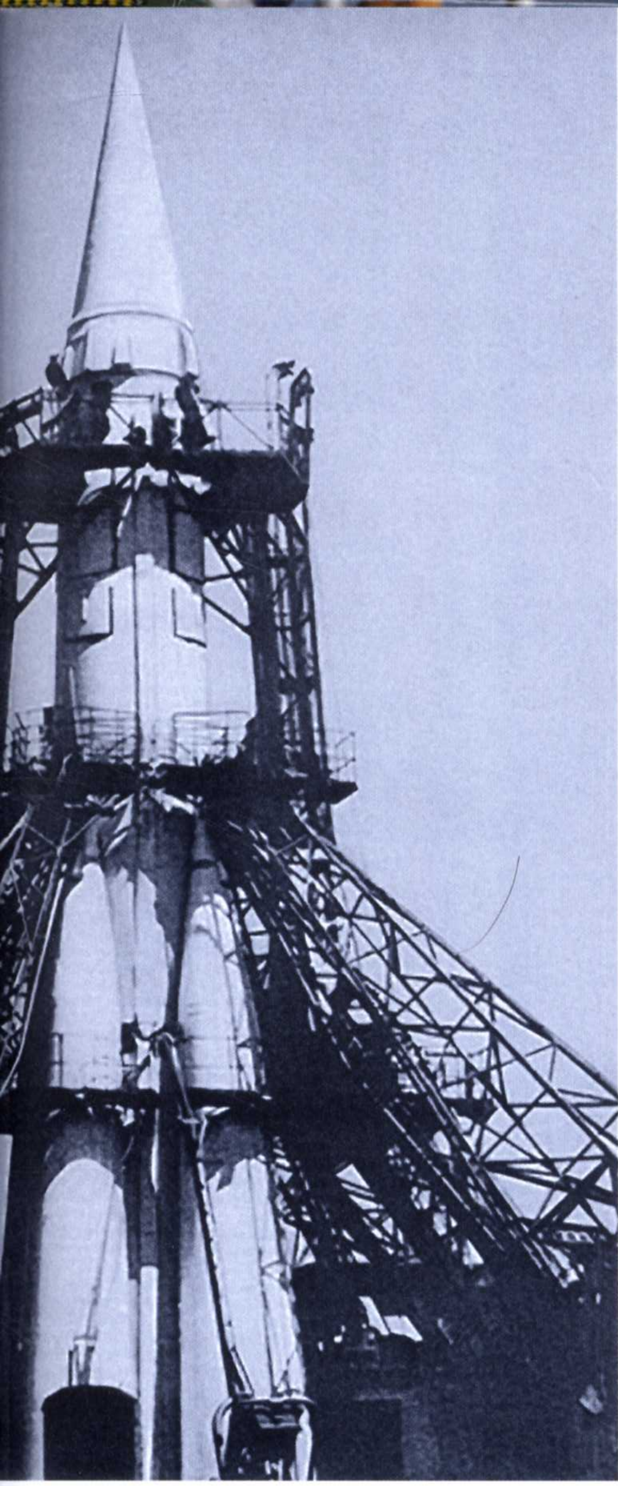


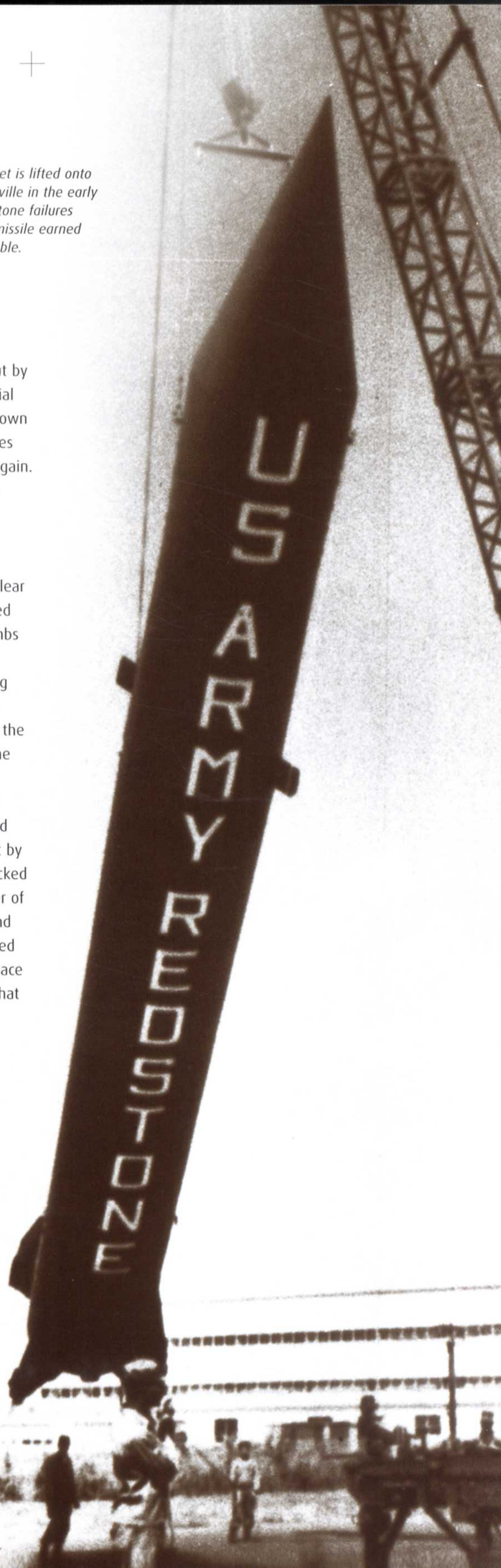
ON THE PAD
The sheer size of the R-7 called for a new type of launch pad at the Tyuratam complex (see p.60). The entire assembly had to be held in place by a series of sloping support gantries that lifted away from the rocket during launch. Beneath the engines, a flame pit caught the exhaust and diverted it away through escape channels so it did not harm the rocket.

HISTORY FOCUS

THROUGH THE SOUND BARRIER

While the engineers at Huntsville and JPL worked on a new generation of rocket-propelled missiles, the National Advisory Council on Aeronautics had other plans. Rockets had potential as powerful engines for a new generation of fighter aircraft, even though jets were still very new technology. In the closing months of the war, Germany had considered a rocket-propelled variant of its Me 262 jet fighter, but this never went beyond a prototype stage. Nevertheless, in 1946, NACA set up an experimental aircraft programme that would produce a wide range of so-called X-planes in the coming decades. The first of these, the stubby XS-1 (later just X-1) was manufactured by Bell Aircraft Inc. Piloted by Chuck Yeager (right), it became the first aircraft to break the sound barrier (see over).





OLD RELIABLE
An early Redstone rocket is lifted onto the test stand at Huntsville in the early 1950s. In service, Redstone failures were so rare that the missile earned the nickname Old Reliable.

captured German scientists were also regularly quizzed during the rocket's long development, but by the early 1950s, they were no longer such a crucial part of the Soviet rocket programme, as home-grown expertise, so devastated in Stalin's paranoid purges of the 1930s and 1940s, began to flourish once again. Before long, most of the captured Germans were allowed to return to their homeland.

Missile delivery

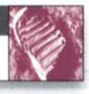
With the successful testing of the first Soviet nuclear weapons in 1949, the pressure for a missile-based delivery system grew. The early Soviet atom bombs were heavier than their US equivalents, and it was clear that the only practical way of deploying them would be with a very powerful rocket – an Intercontinental Ballistic Missile (ICBM). Work on the R-3 was abandoned in order to concentrate on the more ambitious missile.

Korolev and his team ultimately came up with the design officially designated as R-7 (nicknamed Semyorka or Little Seven) and known in the West by the codename "Sapwood". Rather than using stacked stages, each firing in series, the R-7 used a cluster of booster rockets, grouped around a central core and all firing at once. The idea had first been suggested by Mikhail Tikhonravov in 1948 for a proposed space launcher, and fittingly this was to be the rocket that would make spaceflight a reality.

THE ROCKETEERS
This famous picture shows prominent figures working at Huntsville in the early 1950s – left to right are guidance expert Ernst Stuhlinger, Major General Holger Toftoy, Hermann Oberth, Wernher von Braun, and jet aircraft pioneer Robert Lusser.

EXPERIENCE

THE FIRST SUPERSONIC FLIGHT



Pushing the envelope

TOP GUN
Yeager became a pilot just a year after enlisting in the USAF as a mechanic in 1941.

Chuck Yeager's supersonic flight aboard the Bell X-1 was a prelude to the Space Age – an audacious mission with an unpredictable outcome that would shape the coming age of jet aviation. In five hair-raising minutes, Yeager would pass through the sound barrier for the first time and learn what lay beyond.

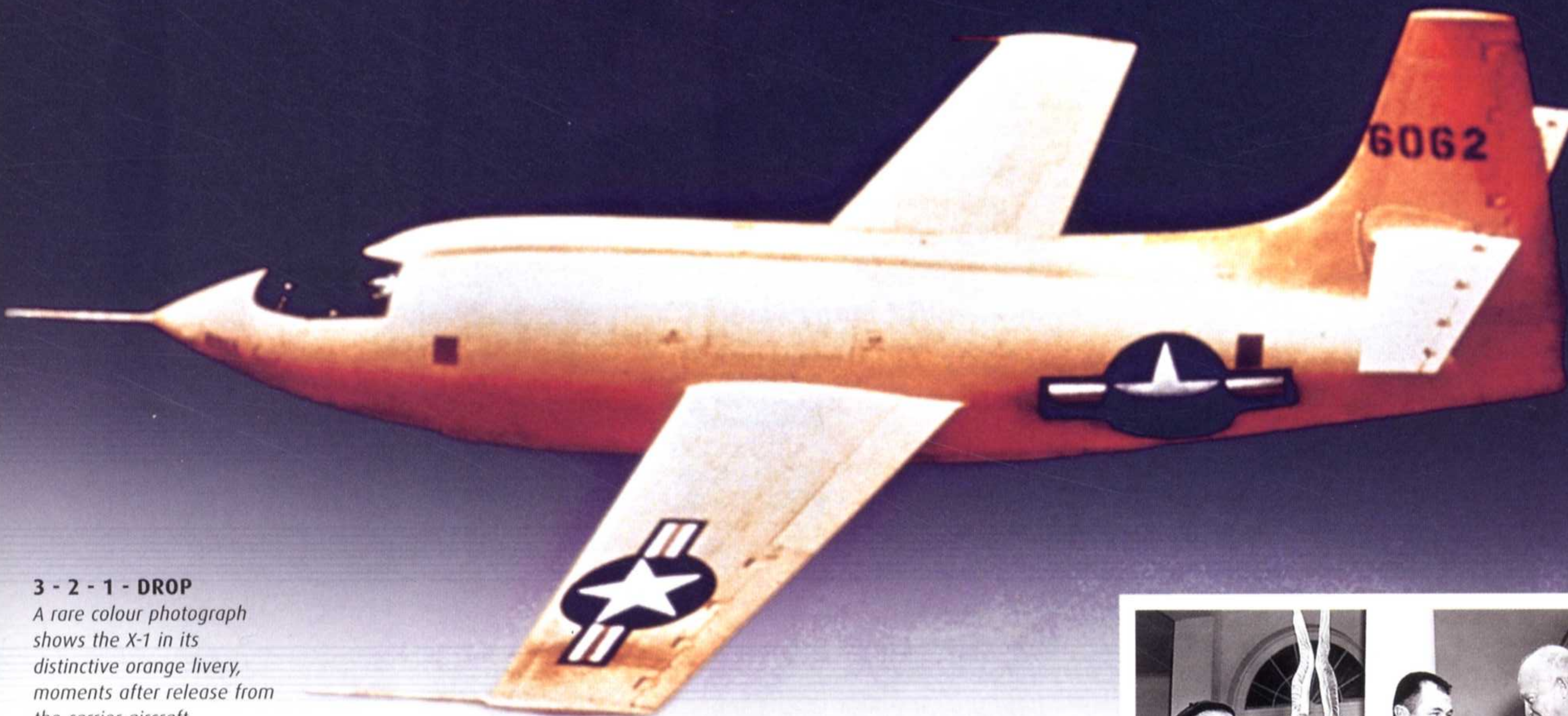
The Bell X-1 had been ordered by the US Army Air Force (as it then was) and the National Advisory Committee for Aeronautics (NACA, the forerunner of NASA), in March 1946. In the aftermath of the Second World War, the full potential of jet fighters was becoming apparent, but there were vital questions that needed to be answered about what would happen when an aircraft went through the sound barrier. For this reason, Bell Aircraft was asked to manufacture three experimental aircraft to be powered by Reaction Motors' new XLR-11 rocket engine. After initial testing at Bell, the aircraft were handed over to the newly formed US Air Force for taking up to, and through, the sound barrier.

"Priorities were, get the airplane **above Mach one** as soon as you can, and don't kill yourself, and **don't embarrass the Air Force**."

Chuck Yeager, looking back on his epic flight

GLAMOROUS GLENNIS
Initially the X-1 was the XS-1 (EXperimental, Supersonic), but this was soon shortened by NACA. Yeager, however, named the aircraft after his wife.

LAUNCH TO LANDING
Taken to high altitude on a B-29 carrier aircraft, Yeager boarded the X-1 through an elevator connecting the bomb bay to the aircraft slung below. Once in the cockpit, he had difficulty closing the hatch – he had cracked two ribs falling from a horse a few days before, but kept quiet about it. With the hatch secured, the B-29 dropped its cargo like a bomb, and seconds later, Yeager triggered the rocket engines. After five historic minutes, he glided back to a landing at Muroc Field, California (now Edwards Air Force Base).



3 - 2 - 1 - DROP
A rare colour photograph shows the X-1 in its distinctive orange livery, moments after release from the carrier aircraft.

HONOURED BY THE PRESIDENT
Yeager was later honoured, along with Bell Aircraft's Larry Bell and John Stack of NACA, at a White House reception. Yeager, who had been accompanied by his parents, later reported that his father, a lifelong Republican, refused to shake hands with Democrat President Truman.

"If you want to grow old as a pilot, you've got to **know when to push it**, and when to back off."

Chuck Yeager reflects on the special skills required by a test pilot

On 14 October 1947, Yeager climbed aboard *Glamorous Glennis* and fired the engines to attempt to break the sound barrier. The flight's communications transcript records the exchanges between Yeager, the project engineer, Captain Jackie Ridley, and the Drop Pilot and project manager, Major Robert Cardenas:

Robert Cardenas: 8-0-0. Here is your countdown: 10 - 9 - 8 - 7 - 6 - 5 - 4 - 3 - 2 - 1 - Drop.

Chuck Yeager: Firing [rocket chamber] four. Four fired okay. Will fire two. Two on. Will cut off four. Four off. Will fire three. Three burning now. Will shut off two and fire one. One on. Will fire two again. Two on ... will fire three again. Three on. **Acceleration good.** Have had mild buffet – usual instability. Say, Ridley, make a note here. Elevator effectiveness regained.

Jackie Ridley: Roger, noted.

CY: Ridley – make another note. There's something wrong with this Machmeter. It's gone screwy!

JR: If it is, we'll fix it – personally, I think you're seeing things!

Yeager had, in fact, passed through the sound barrier while his instruments indicated a speed of Mach 0.96, leaving the turbulence behind as he did so. Seconds later, and still climbing, he shut off the rocket engines with 30 per cent of their fuel remaining, and prepared for the glide home.

REMEMBERED ON FILM
Yeager's supersonic flight plays a pivotal role in Tom Wolfe's book The Right Stuff, *an account of relations between the test pilot community and the Mercury Seven astronauts, later filmed with Sam Shepard (above) as Yeager.*

Reaching for orbit

While the missile programmes of the rival superpowers moved steadily forwards in the 1950s, enthusiasts on both sides were convinced that the same technology could be used for the exploration of space. The announcement of a forthcoming International Geophysical Year (IGY) of scientific study would finally spur their superiors into action.

A MOUSE IN SPACE?
Delegates at a 1954 New York symposium inspect a model of Dr. Fred Singer's MOUSE (Minimum Orbital Unmanned Satellite of Earth), a US project proposed in the early planning stages of the IGY but later shelved.

By the early 1950s, many in the scientific community felt that space travel was an idea whose time had come. Ideas of launching a person into space still seemed outlandish, but the prospects for putting some kind of artificial satellite into orbit seemed promising. Hawkish thinkers and military powers on both sides also saw the advantages. Space might become an important new front in the Cold War and a vital strategic element if the Cold War ever became "hot".

Struggling into space

In the United States, the main obstacles were political – space exploration was not only off the agenda, it was still not even seen as a practical possibility. When presented with a preliminary plan to send a small satellite into orbit in time for the IGY of 1957–58, President Harry S. Truman dismissed it as "hooey".

But the space advocates were not deterred, and they set about appealing directly to the public. Coordination was key, and in 1951 Willy Ley organised a Symposium on Space Travel, bringing together enthusiasts and engineers ranging from the Huntsville missile team to the amateurs of the American Rocket Society. Soon memos were exchanged about the best way to sell the dream of space travel to America. Cynics wryly commented that the US would commit itself only if the Soviets threatened to get there first.

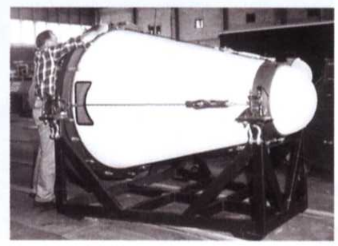
By mid-1954, things began to move, as von Braun was approached by the Office of Naval Research to take part in a summit of leading scientists that would examine the various satellite proposals already on the drawing board and look for a way forward. The result was a proposal for Project Orbiter, a cheap launch system based on the Redstone rocket, topped with a second stage powered by cheap solid rockets. Von Braun was sure it could put a satellite weighing a few kilograms into orbit during the IGY.

But in the spring of 1955, with work on Project Orbiter already advancing, a series of political setbacks saw von Braun excluded from US plans for space. One attack came from scientists involved in the IGY, who dismissed the Orbiter plan as inelegant and argued that the first US satellite should be an all-American affair. These objections might have been overcome, were it not for a turf war between the military branches. Alarmed at reported developments

TECHNOLOGY

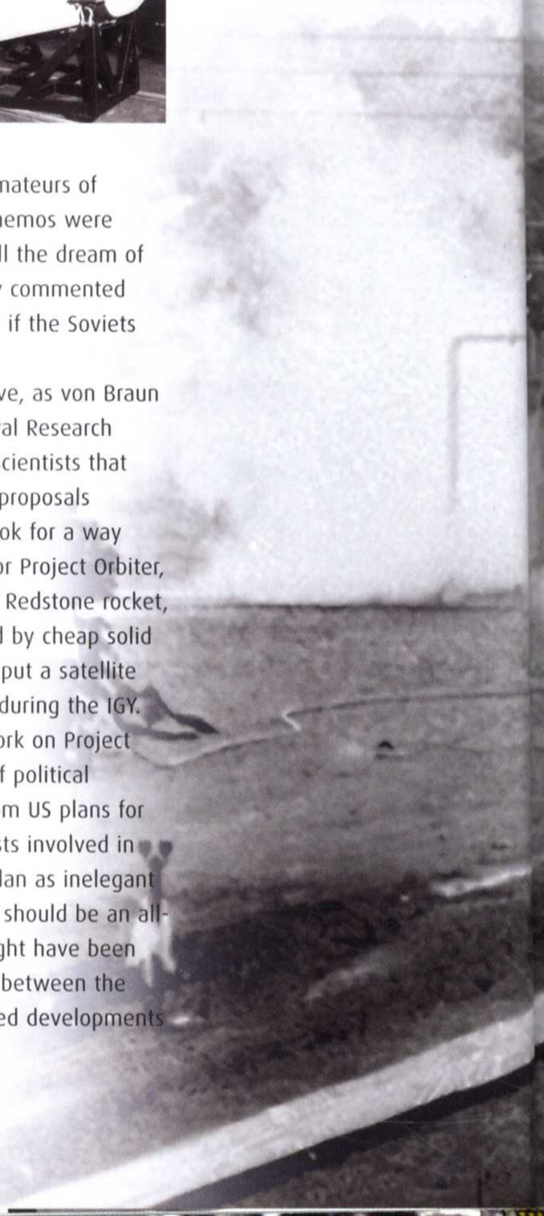
THE FIRST RETURN FROM SPACE

Within a week of the decision to abandon Project Orbiter, the US Defense Department threw a lifeline to Huntsville when it authorized the Army's development of the Jupiter Intermediate-Range Ballistic Missile (IRBM). Jupiter missiles would follow a trajectory that left and re-entered Earth's atmosphere, so permission was given for a programme of Redstone-based test vehicles that could take Jupiter components such as warhead nose cones into space and test how they survived the heat of re-entry. The resulting Jupiter A and C rockets were very similar to the original Project Orbiter.

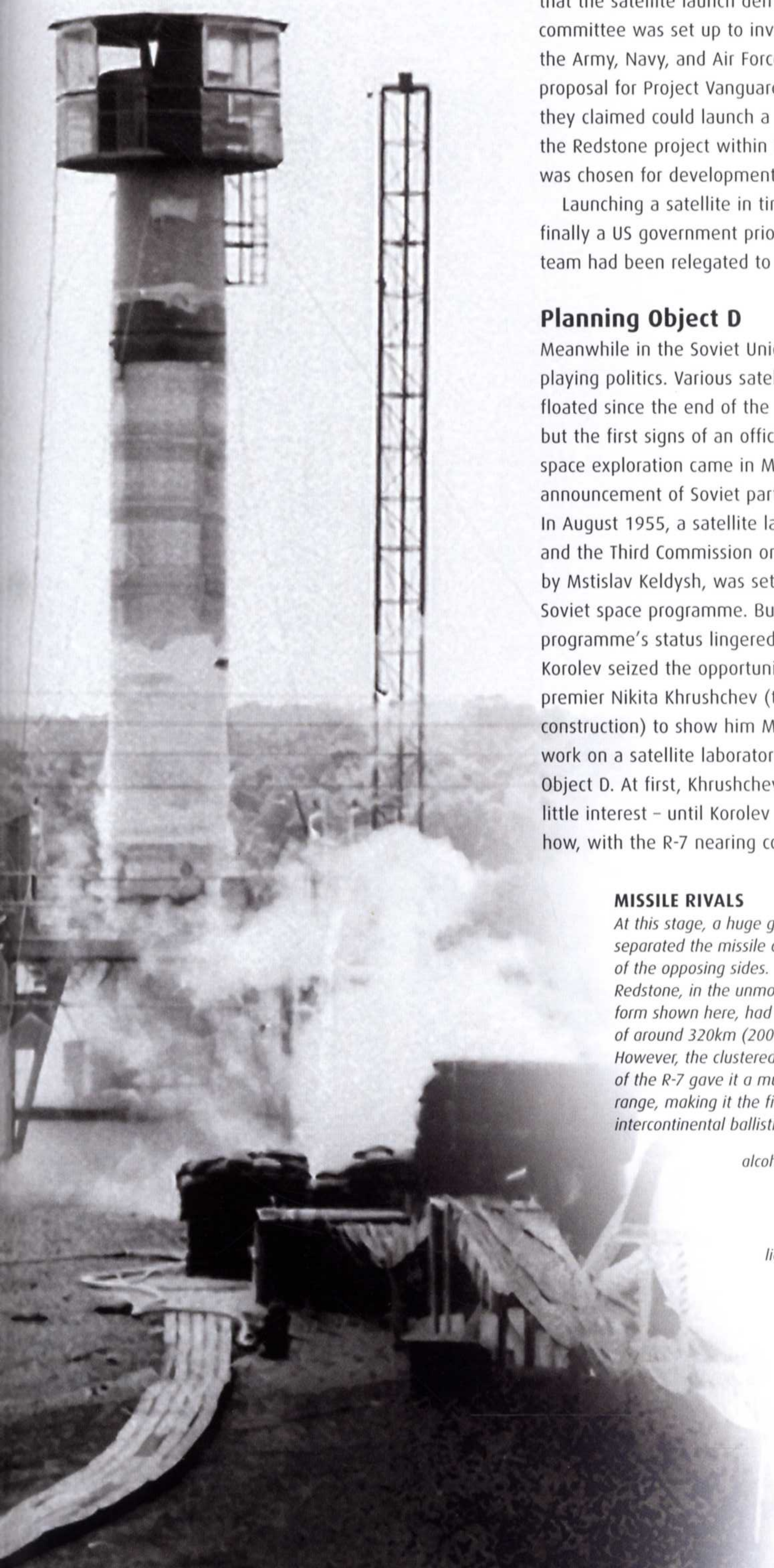


The first object to successfully return to Earth from space was a model Jupiter nose cone, launched on 8 August 1957.

PROJECT JUPITER
The first Redstone took to the skies on 20 August 1953. Over the following years, von Braun's team refined it into variants such as the Jupiter A and C. These multi-stage rockets, both developed as part of the Army's plans for the Jupiter IRBM, borrowed ideas from Project Orbiter. Ultimately the Jupiter C, renamed Juno, would act as launcher for the first US satellite.



TESTING REDSTONE
Exhaust billows from the base of a Redstone rocket during a static test-firing of the engines. The test stand at Redstone Arsenal allowed the Huntsville engineers to measure the amount of thrust their rocket engines could generate. With the Army unwilling to fund large building projects at the site, the Germans were forced to build the stand on a tight budget, effectively raiding the petty cash.

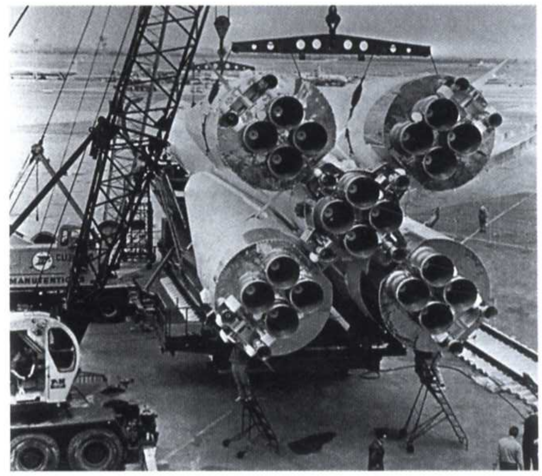


in the Soviet Union, President Eisenhower decided that the satellite launch demanded his attention. A committee was set up to investigate options from the Army, Navy, and Air Force, and the Navy's proposal for Project Vanguard, a three-stage rocket they claimed could launch a heavier payload than the Redstone project within the same time frame, was chosen for development.

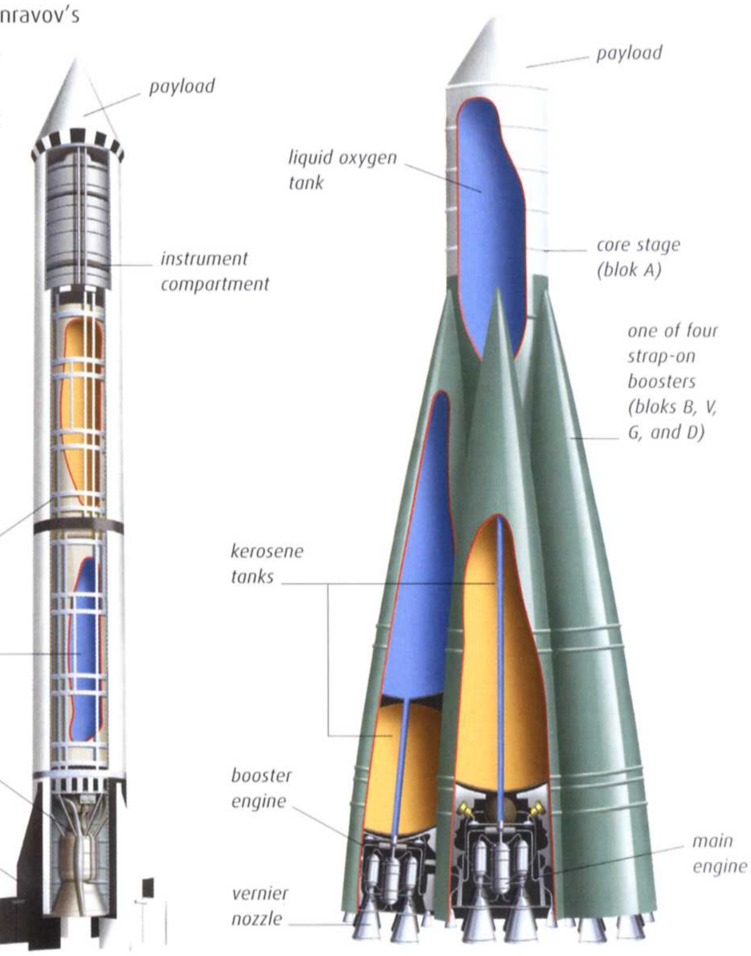
Launching a satellite in time for the IGY was finally a US government priority, but the Huntsville team had been relegated to the sidelines.

Planning Object D

Meanwhile in the Soviet Union, Korolev was also playing politics. Various satellite projects had been floated since the end of the Second World War, but the first signs of an official commitment to space exploration came in March 1954, with the announcement of Soviet participation in the IGY. In August 1955, a satellite launch was approved, and the Third Commission on Spaceflight, chaired by Mstislav Keldysh, was set up to coordinate the Soviet space programme. But uncertainties over the programme's status lingered, until in January 1956, Korolev seized the opportunity of a visit by Soviet premier Nikita Khrushchev (to inspect the R-7 under construction) to show him Mikhail Tikhonravov's work on a satellite laboratory known as Object D. At first, Khrushchev showed little interest – until Korolev pointed out how, with the R-7 nearing completion, the Soviet Union would be able to launch a satellite far larger than anything the Americans could hope for. Enticed by the chance to humiliate the United States, Khrushchev gave the project his backing. Tikhonravov's team were transferred to Korolev's OKB-1, and the project became a top priority. The Space Race was about to begin.



ENGINE ARRAY
The base of an assembled R-7 displays 20 large nozzles – four on each of the booster RD-107 engines, and four for the central RD-108. Smaller vernier nozzles were used to steer the rocket.



US Redstone launcher

Soviet R-7 (Semyorka)

MISSILE RIVALS
At this stage, a huge gulf separated the missile capabilities of the opposing sides. The Redstone, in the unmodified form shown here, had a range of around 320km (200 miles). However, the clustered design of the R-7 gave it a much longer range, making it the first truly intercontinental ballistic missile.

JANUARY 1959: WINDS OF CHANGE
A technician examines a boilerplate Mercury capsule prior to testing its performance in the huge wind tunnel operated by NASA's Space Task Group at Langley, Virginia.

THE DAWN OF THE SPACE AGE

BY 1957, both the Soviet Union and the United States had the technology to put a satellite in space – the question of who would be the first to do it was largely one of political willpower. Korolev's team had to deal with a hasty satellite redesign in order to have something ready to launch, while von Braun's group were sidelined – and the replacement naval rocket team faced problems of their own. However, no one could have predicted the seismic effect that the first space launches had on the imagination of the general public. Americans were shaken out of their complacent belief in a technologically backward Soviet Union, while Soviet Premier Nikita Khrushchev soon realized the propaganda value of his nation's new-found space superiority.

The late 1950s and early 1960s, then, saw the beginnings of a Space Race, as the rival superpowers attempted ever more daring technological feats in the effort to claim new firsts. Most daring of all were the efforts to launch the first manned spacecraft – programmes that would create a new breed of hero for a modern age: the spaceman.

Red star in orbit

A new era of exploration began on 4 October 1957, as Sputnik 1 began its transmissions from high above the Earth. And the beeps from the satellite's radio were also a clear signal of Soviet space superiority.

25 January 1957
The Soviet government orders that plans be made for the launch of a basic satellite following delays to the design of Object D, initially intended for the first launch.

15 May 1957
The first test-firing of a Soviet R-7 two-stage ICBM, core of the eventual Sputnik launch vehicle, is unsuccessful.

21 August 1957
A Soviet R-7 ICBM (codenamed Sapwood by Western intelligence) launches successfully from Tyuratam.

4 October 1957
A modified R-7 launch vehicle lifts off from Tyuratam carrying Sputnik 1. The Soviet news agency TASS announces the successful launch to the world.

25 October 1957
Sputnik's batteries run down and its radio signal ceases.

4 January 1958
Sputnik 1 burns during atmospheric re-entry.

But Sputnik 1, an 83-kg (184-lb) steel ball some 58cm (23in) across, and containing little more than a basic radio transmitter, was still a long way from Tikhonravov's ambitious Object D orbital laboratory. Just what had happened to derail Soviet plans for a more spectacular entry into the Space Age?

The birth of Sputnik

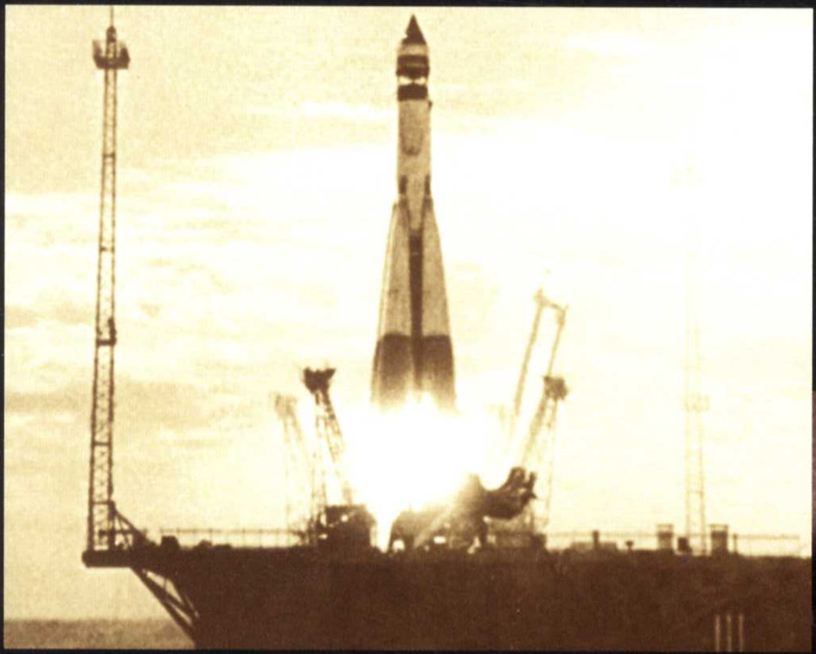
Ultimately, plans to develop Object D in time for a 1957 launch had fallen victim to the same problems encountered time and again in the early days of the space programme – bureaucracy and politics. Despite a promising start and direct approval from the Soviet head of state, the satellite had fallen behind schedule due to the unwillingness of other institutions to cooperate with the mysterious requirements of OKB-1. To take just one example, there were repeated delays to the delivery of high-quality silicon that the Department of Chemistry was supposed to be supplying for Object D's solar cells. By September 1956, it was clear that the project was in trouble, and Mstislav Keldysh of the Commission on Spaceflight said as much at a meeting of the Academy of Sciences. Korolev knew there was now a risk that the United States might achieve a launch while the Soviet satellite was still under construction. Against Keldysh's wishes, he began development of a much smaller and more achievable satellite, which he named Prosteshii Sputnik – Project Sputnik (PS), or "Companion".

Early in 1957, Korolev revealed his contingency measures to the Soviet leadership. The plan required two small PS models and a new "shroud" to cap the R-7 and protect the satellite on its way to orbit. The revised project was approved and made OKB-1's top priority (contingent, of course, on the successful launch of the R-7) in late January.

Testing the R-7

While work on the new PS satellites got under way, pressure was also growing on the R-7 project. In May 1957, the first missile arrived at the Tyuratam launch complex (see p.59). But a launch attempt on 15 May ended in failure 100 seconds into the flight, as one of the strap-on boosters caught fire and exploded due to a fuel leak. Modifications were made to prevent a repeat performance, but other problems appeared in the second and third tests. Finally, on 21 August, an R-7 made it nearly all the way to its target zone on the remote Kamchatka Peninsula before its warhead disintegrated. Another launch on 7 September ended in the same way – there was clearly work to be done before the R-7 could be a dependable ICBM, but its lower stages were now seen as reliable enough to attempt a satellite launch.

GETTING THE MESSAGE
Most Americans waking on the morning of 5 October 1957 were alarmed to learn that a Soviet satellite had flown over their heads at least four times as they slept. For President Dwight D. Eisenhower, it was a shocking sign of Soviet technological parity – and potential superiority.



DOUBLE CELEBRATION
The Sputnik launch (above) not only showed Soviet superiority in rocketry, it was also the first time the R-7 missile had performed flawlessly – another reason for Soviet premier Nikita Khrushchev (right) to be happy with the results.

"... the new socialist society turns even the **most daring** of man's **dreams** into a reality."

Official TASS press statement, 4 October 1957

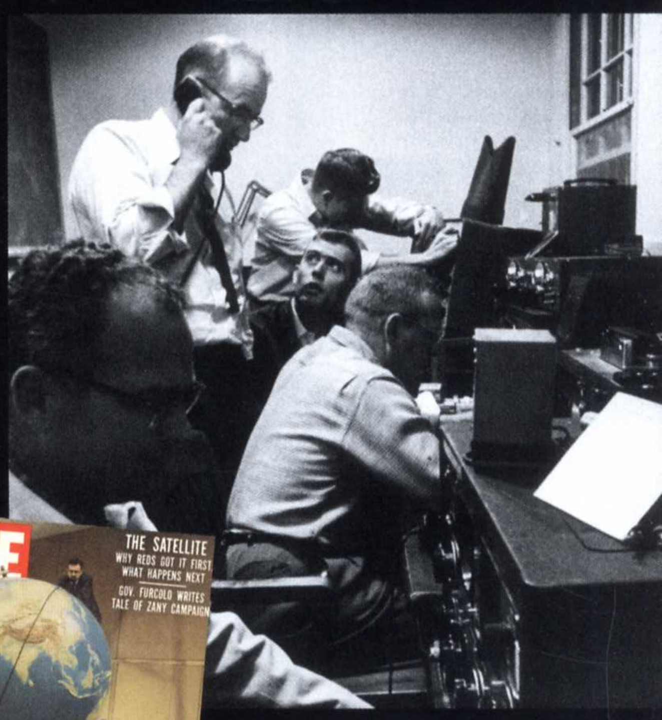
SPUTNIK IN ORBIT
As it separated from the shroud and the core rocket stage, Sputnik released four long radio antennae, between 2.4 and 2.9m (94 and 114in) long. The "beeps" they broadcast carried data about pressure and temperature encoded in their duration.

INSIDE SPUTNIK 1
Although basic, every aspect of the first satellite had a scientific purpose. The ball-like shape would aid calculations of atmospheric drag (which eventually pulled the satellite to its doom three months later), while the pressurized internal sphere was a prototype for a passenger cabin.

Countdown to launch

On 20 September, the State Commission met to approve the launch, initially setting the date for 6 October. But rumours soon spread of an American scientific paper, due to be presented on that day at an IGY conference in Washington, entitled "Satellite in Orbit". Although Soviet intelligence was confident that the US was only planning a sub-orbital launch (see over), Korolev did not want to miss his date with history by a whisker, and the launch was duly moved forward two days.

At 10:28pm Moscow Time on 4 October 1957, a modified R-7 carrying the PS-1 satellite fired its engines to rise clear of the launch pad at Tyuratam. The ascent went flawlessly, as did the separation of Sputnik 1, as the little satellite became known, from the central rocket stage. However, by the time Sputnik had unfolded its antennae and begun to transmit, it had passed beyond the range of Soviet receivers. There was an anxious 90-minute wait for its next passage across the sky, when a steady stream of beeps confirmed Sputnik was in a stable orbit ranging from 215 to 939km (133 to 583 miles) above the Earth. The Space Age had begun.



CAUGHT ON THE HOP
Sputnik's flight was monitored by scientists across the world, such as those at the Stanford Research Institute in the USA (above). Scientific interest was mingled with concern about what a Soviet presence in space could mean.

1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

1 May 1957
A Vanguard first and third stage launch a dummy satellite on a suborbital path.

4 October 1957
News of the successful launch of Sputnik 1 spreads around the world.

23 October 1957
The Vanguard TV-2 rocket, with functioning first and second stages and an inert third stage, launches successfully. In view of the Sputnik 1 launch, the decision is made to attempt a satellite launch as part of the TV-3 test flight.

8 November 1957
Von Braun's Army-based Project Orbiter is restarted, under orders to launch a satellite within 90 days.

6 December 1957
The US Navy Vanguard rocket TV-3 fails on launch from Cape Canaveral.

The US responds

Caught completely off-guard by the Soviet launch of Sputnik 1, the United States rushed to respond with a satellite launch of their own. But as poor decisions came back to haunt them, the launch ended not in triumph, but in humiliation.

News that the Soviet Union had launched a satellite first reached the US on the evening of 4 October 1957. Scientists at the IGY meeting in Washington queued to congratulate the gleeful Soviet delegation. At Huntsville, Wernher von Braun was entertaining a group of VIPs including the new Secretary of Defense and the Army's Chief of Staff when the news broke. After proclaiming, "Today, man has taken his first step towards Mars," von Braun turned to lobbying his visitors on the importance of restarting his Redstone-based launch vehicle programme (see p.48).

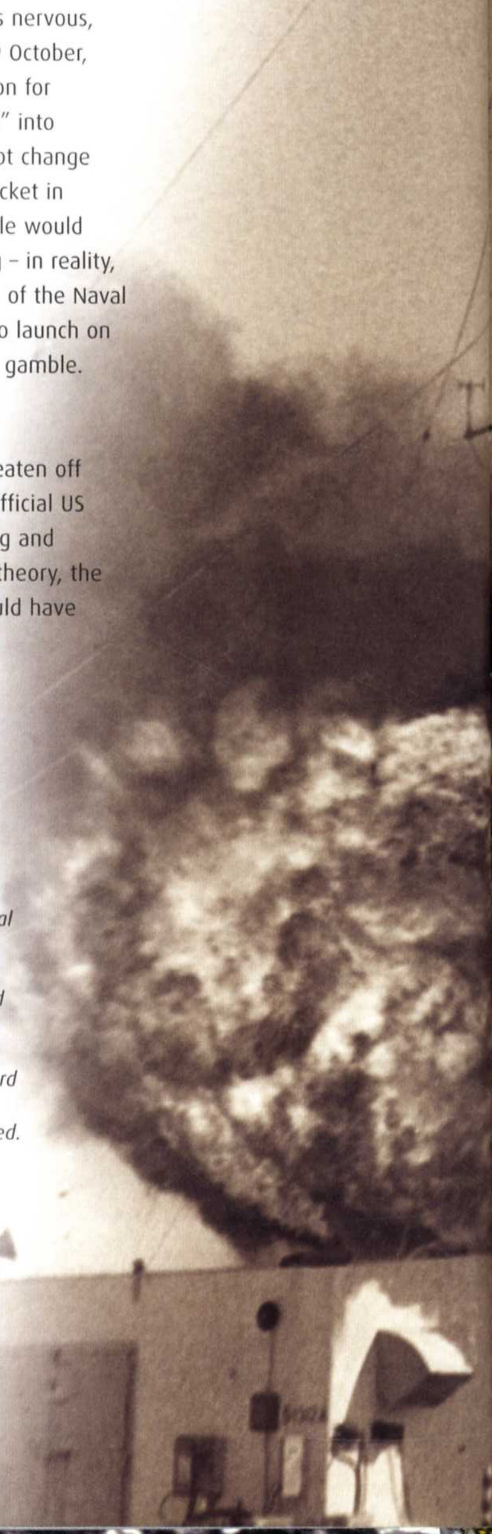
In the White House there was consternation, as much over the intelligence failure as over Sputnik 1 itself. For years, the CIA had dismissed Soviet space promises as propaganda and the idea that a Russian satellite could outperform US efforts as fantasy. The level of surprise was well expressed by James M. Gavin, Army Chief of Research and Development, who likened Sputnik to a "technological Pearl Harbor" – the US had lost a seemingly one-horse race.

While the inquests would rumble on, the immediate question was how to respond. Eisenhower faced a difficult decision – he felt that the missile gap, as it was known, was largely a public misconception, fed by a need for secrecy about America's missile programmes and its intelligence-gathering capabilities. The Redstone rockets, now under the control of the Army Ballistic Missile Agency (ABMA), were increasingly reliable, while the longer-range Atlas and Titan ICBM programmes of the Air Force and Navy were progressing well. Meanwhile, U-2 spy planes provided a good idea of the state of the R-7, or Sapwood, as it was known in the West.

Nevertheless, the American public was nervous, and a swift response was called for. On 9 October, Eisenhower congratulated the Soviet Union for its launch of what he called a "small ball" into space. He insisted that US plans would not change and announced a test of the Vanguard rocket in December. The implication that the vehicle would have been ready anyway was misleading – in reality, the Vanguard team, run by John P. Hagen of the Naval Research Laboratory, knew that rushing to launch on Eisenhower's timetable was a dangerous gamble.

Vanguard stumbles

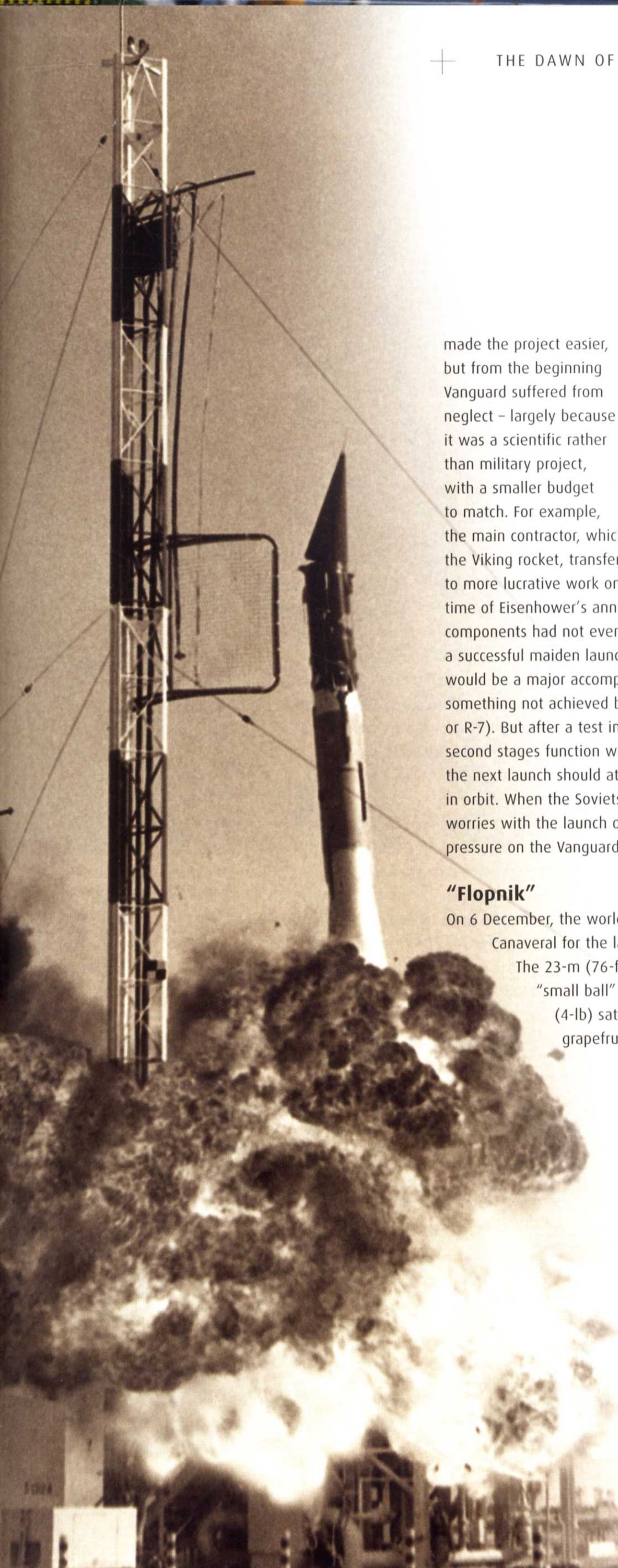
The US Naval research rocket that had beaten off the Redstone challenge to become the official US satellite launcher was a hybrid of existing and new rocket stages (see panel, right). In theory, the use of tried-and-tested components should have

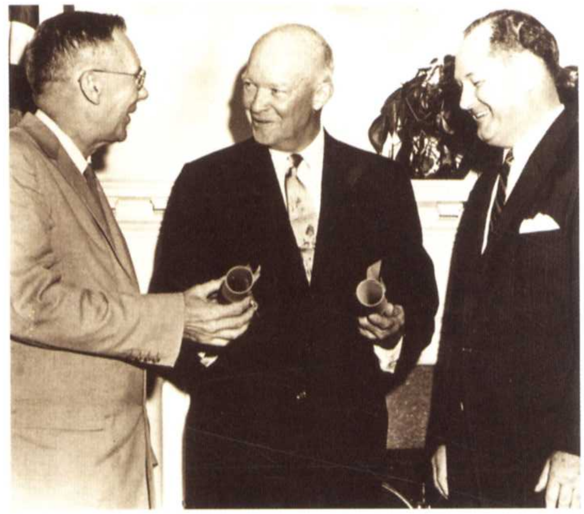


LAUNCH PAD FIASCO
After winning the battle with von Braun's US Army team to be the first to launch a satellite, the US Navy's Vanguard rocket explodes on the launch pad, watched on television by millions of dismayed Americans.

UNDER NEW MANAGEMENT
With the establishment of the Army Ballistic Missile Agency (ABMA) at Redstone in 1956, von Braun's team came under the command of Major General John B. Medaris (on the left in this picture with von Braun).

STANDING READY
By mid-1957, the Huntsville team had successfully used their Redstone-based Jupiter C rocket to reach space (see p.38). Medaris ordered that several of the missiles should be held back for a potential satellite launch, but the Department of the Army was so concerned that the ABMA might "accidentally" launch a satellite before Vanguard that they insisted the upper stages be disabled.





NASA IS BORN

On 21 November 1957, members of the US Satellite Committee for the IGY wrote to several influential figures recommending the formation of a civilian agency to manage the space programme. Within a year, Eisenhower had established NASA, with T. Keith Glennan (right) as Administrator and Hugh Dryden (left) as his deputy.

made the project easier, but from the beginning Vanguard suffered from neglect – largely because it was a scientific rather than military project, with a smaller budget to match. For example, the main contractor, which had previously built the Viking rocket, transferred its experienced staff to more lucrative work on the Titan ICBM. At the time of Eisenhower's announcement, the Vanguard components had not even been test fired together – a successful maiden launch for the complete vehicle would be a major accomplishment in itself (and something not achieved by either the V-2, Redstone, or R-7). But after a test in October saw the first and second stages function well, Washington insisted that the next launch should attempt to put a US satellite in orbit. When the Soviets compounded American worries with the launch of Sputnik 2 (see over), pressure on the Vanguard team could only increase.

"Flopnik"

On 6 December, the world's press gathered at Cape Canaveral for the launch of Vanguard TV-3. The 23-m (76-ft) vehicle carried a truly "small ball" in its nose cone – a 1.8-kg (4-lb) satelllite about the size of a grapefruit. The launch had already been postponed twice on preceding days due to poor weather, but on the third day all seemed fine, and the countdown went as planned, watched by millions of television viewers across the country. At 11:44am, the rocket's engines fired, and it slowly began to lift off the launch pad, rising to an altitude of 1.3m (4ft) before, two seconds after launch, a huge explosion tore the first stage apart, sending the upper sections toppling into the flames. To rub salt in the wound, the satellite itself escaped the inferno, rolling free and transmitting its beeps to anyone with a radio. America's first step into space had gone up in flames – drastic action would be needed to restore US dignity.

TECHNOLOGY

THE VANGUARD LAUNCHER

At 23m (76ft) tall but just 1.14m (46in) across at its broadest, the Vanguard was the epitome of a tall, elegant rocket, certainly when compared with the more squat appearance of the Redstone missile and its variants. The first stage, powered by a mix of liquid oxygen and kerosene, was designed by General Electric based on the successful Viking rocket. The second stage used an engine similar to those used on the Navy's Aerobee sounding rockets, burning a mix of nitric acid and unsymmetrical dimethylhydrazine (UDMH). This stage contained the rocket's guidance systems – with no fins in the design, the rocket's attitude was controlled by tilting the exhaust nozzles on gimbals. The upper stage, a solid-propellant rocket built by the Grand Central Rocket Company, was set spinning during separation in order to stabilize it.

1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

12 October 1957
After the success of Sputnik 1, Khrushchev orders Korolev's satellite and launch teams to quickly build and launch a much larger satellite, that would be capable of carrying a dog.

3 November 1957
Sputnik 2 is launched from Tyuratam carrying the dog Laika onboard. She dies from stress and overheating within a few hours following a system failure.

7 November 1957
Sputnik 2's transmitters fail, leaving Laika's fate a mystery.

10 November 1957
For many years, this was the official date of Laika's death, when her food and oxygen would have run out.

14 April 1958
Sputnik 2 falls out of orbit, re-entering the Earth's atmosphere.

Laika's travels

Within a month of their initial satellite launch, the Soviet Union again stunned the world with the launch of a much larger Sputnik, this time carrying a passenger – the first living creature in orbit.

Basking in the success of Sputnik 1, the OKB-1 team prepared for a well-earned break in early October 1957 – only to find that Nikita Khrushchev had other ideas. The Soviet premier, his interest in space fired by the reaction in the Western press, telephoned Sergei Korolev on 12 October to congratulate him in person and ask what he planned to do next. With Object D still not ready and a spare R-7 (Sputnik 1's backup) at Tyuratam, there was a clear opportunity to press home Soviet superiority with the launch of a heavier satellite. Knowing that they still had some equipment in stock from earlier test launches that had carried dogs to the edge of the atmosphere and returned many of them unharmed, Korolev suggested that the first launch of an animal into orbit would offer both scientific and propaganda advantages.

DOGS IN SPACE
Dogs played the same role in early Soviet space exploration that primates played in the US. Here, Korolev is pictured with one of two dogs that successfully reached an altitude of 100km (60 miles) aboard an R-1D rocket in July 1954.

And so Korolev rapidly recalled his team from holiday to work on the construction of Sputnik 2. Often working from Korolev's sketches rather than properly drafted plans, OKB-1 was under orders from Khrushchev to launch the satellite within a month. In retrospect, their achievement was remarkable, and it seems likely that Korolev had in fact made some early plans during the development of Sputnik 1.

Building the satellite

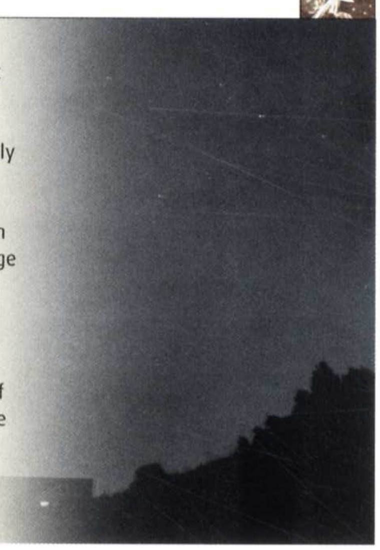
Sputnik 2 provided the first opportunity to get real scientific data from orbit. The basic spacecraft design was conical. At the narrow end, an array of sensors was fitted to measure high-energy radiation from the Sun. Behind these sat a pressurized sphere – the core of the original PS-2 satellite, now fitted with more sophisticated radio transmitters for returning data from orbit. At the base of the craft was a cylindrical, pressurized module within which the unfortunate canine would travel.

Korolev's team had already developed sensors to monitor the health of dogs during rocket flights, but a longer flight would create new challenges. Insulation would be needed to maintain a steady temperature despite the intense variations outside the satellite. Food, water, and air would have to be regulated, and the carbon dioxide breathed out by the animal would have to be filtered from the air

PREPARED FOR LAUNCH
Sputnik 2 was cramped, but still had room for Laika to lie down. She was strapped in two days before launch, so that she could become used to the conditions.

HISTORY FOCUS

A SOVIET TRAIL ACROSS THE SKY



One of Sputnik 2's major achievements was to disprove a vocal minority who had claimed that Sputnik 1 was nothing but a Soviet hoax. Since the 1920s, the Western world had been led to believe that the Soviet Union was technologically backward and incapable of innovation. Even when the first Soviet nuclear weapons were tested, many assumed that they were reliant on technology stolen from the West. For the average Western citizen, the arrival of Sputnik 1 was a traumatic event, so it was little wonder some people were in denial. Sputnik 2, however, was large enough to be visible to the naked eye as it moved across the night sky. The satellite itself did not have a source of light onboard – it shone only by reflecting sunlight – but long-exposure photographs such as this one provided physical evidence of a new object in Earth's sky.

LAIKA LIVES ON
Laika's image became an icon of the early Space Age, used on stamps, postcards, and even cigarette packets in the Soviet Union and beyond.

before it built up in poisonous quantities. There was also the delicate question of how to handle the dog's physical waste in weightless conditions.

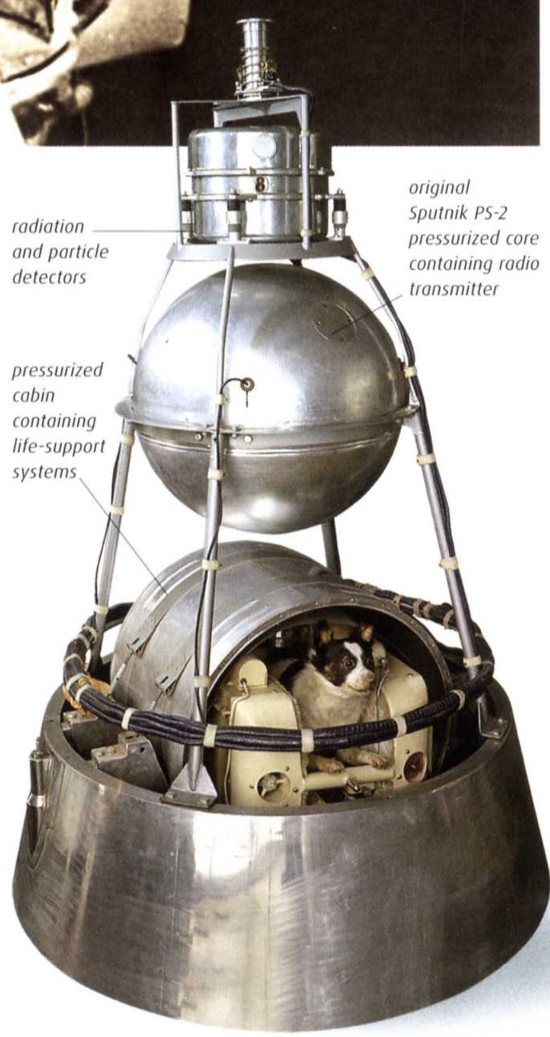
A dog's life

Laika (her name means Barker) was one of ten animals considered for the flight. All the dogs used were light-coloured mongrel bitches – light so they would be seen by onboard cameras, mongrels because they were considered more robust, and bitches to simplify the design of "nappies" used to handle body waste. Laika was found wandering the streets of Moscow and trained to tolerate increasingly confined spaces prior to launch. She was ultimately selected for the mission by Oleg Gazenko, an expert in the developing area of space medicine.

Sputnik 2 took to the skies on 3 November 1957, and within hours the Soviet Union was trumpeting its latest coup. The satellite weighed 508kg (1,117lb) and entered orbit still attached to the exhausted 6,800-kg (15,000-lb) core stage of its R-7 rocket. State press agency TASS reported that Laika was adjusting well to the pressures of spaceflight, but that since it would be impossible to return her to Earth, the spacecraft carried a system to painlessly put her to sleep after ten days in orbit, before her food, water, or air supplies ran low. Regular updates followed, but nothing more was heard after a radio failure on 7 November. To the outside world, it was generally assumed that Laika had died of natural causes about one week into her flight.

It took 45 years and the collapse of the Soviet Union for the true story of Laika's fate to emerge. While the launch itself was a success, and Laika's heart rate rapidly fell back to normal levels, it seems that the satellite and core rocket stage were actually intended to separate. When the separation failed, it tore away some of the protective insulation, and also caused a malfunction in the thermal control system. Temperatures in the capsule rose rapidly to 40°C (104°F), and Laika's heart rate began to rise again. She died around six hours into the flight, from a combination of heat and stress.

Laika was one of the few animal casualties of the space programme, and the only one to have been sent into space with no hope of return. It is almost certain that, if time had allowed, Korolev would have attempted to design some form of re-entry capsule – not only could this have saved the dog, it could also have provided more useful scientific information. The flight made Laika the most famous dog in history, but in 1998 a reflective Oleg Gazenko said, "The more time passes, the more I am sorry about it. We did not learn enough from the mission to justify the death of the dog."



INSIDE SPUTNIK 2
Sputnik 2 had similar dimensions to Object D, allowing it to fit into the standard R-7 nose cone. This model has had the outer shielding removed.

8 November 1957
Following the failure of the Navy's Vanguard rocket, Project Orbiter is formally restarted, under orders to launch a satellite within 90 days.

31 January 1958
A Juno 1 rocket successfully puts the Explorer 1 satellite into orbit.

5 March 1958
An attempted launch of Explorer 2 fails when the upper rocket stage of its launch vehicle misfires.

17 March 1958
A US Navy Vanguard rocket finally succeeds in placing a small satellite, known as Vanguard 1, into orbit.

26 March 1958
Explorer 3 is successfully launched with another Juno I rocket.

23 May 1958
Explorer 1's batteries fail, and it ceases transmission of information, though it remains in orbit for another 12 years.

26 July 1958
Explorer 4 is successfully launched.

24 August 1958
The launch of Explorer 5 fails due to a problem with booster rocket separation.

The US reaches orbit

With Sputnik 2 capturing headlines around the world, the US government finally allowed Army planning for a spaceshot to resume. In the wake of Vanguard, Explorer 1 would become the first American satellite.

The same evening that news of Sputnik 1 had broken, Secretary of Defense Neil McElroy, who happened to be visiting Redstone Arsenal, had called Wernher von Braun's bluff – if the Army team were allowed to restart work toward a satellite launch, how soon could they have something in orbit? Sixty days, said the optimistic von Braun, while his more cautious commander, John B. Medaris, thought that 90 days was more feasible.

Nevertheless, it took the launch of Sputnik 2, and the realization that the Soviet space programme was not just a one-off publicity stunt, to force a decision in Washington. On 8 November, the Huntsville team was given approval to launch a satellite, with several provisos. The most important of these was the nature of the satellite – Eisenhower, in particular, still had reservations about using a military launcher in the space programme, and so it was decreed that the satellite must carry an instrument package to do some real science (and just perhaps to help them leapfrog the Russians).

While the launcher would be a modified Jupiter C (the refined Redstone that the team had completed and tested earlier in the year), the satellite would have to be designed from scratch. William H. Pickering of the Jet Propulsion Laboratory (JPL) in California (at the time a development facility for short-range missiles) successfully lobbied Medaris to allow his team to build the satellite, while the Huntsville group concentrated on readying the launch vehicle. It was to be the first of many satellites that would be developed at the laboratory. In order to simplify the design, the satellite, soon christened Explorer 1, was modified from one of JPL's Baby


1ST U. S. SATELLITE LAUNCHED, ORBITS IN SPACE WITH SPUTNIK

NEW MOON IS LOFTED TO SKY-RIDING PATH BY JUPITER-C MISSILE

Latest Space Explorer Soars To 2,000 Miles At Farthest Point And 230 At Nearest— Attains Speed Of 15,400 Miles An Hour

DEFENSE NO VOTE ISSUE, NIXON SAYS

PROBERS LINK HEAD OF UNION TO MOBSTERS

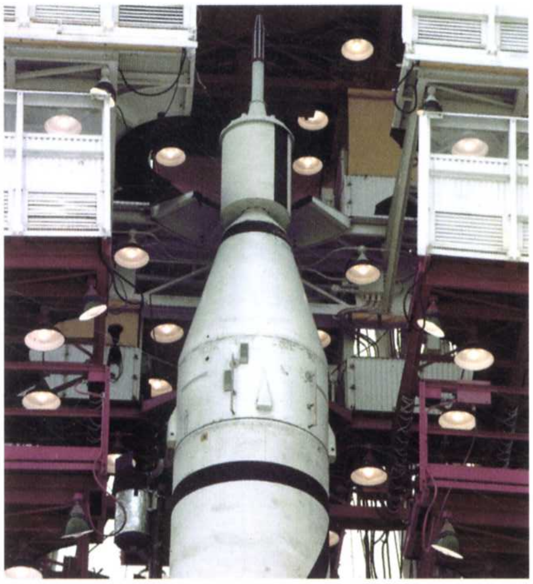
BIPARTISAN FRONT URGED

Aid Pact Will Flood Egypt With Russians

IKE INFORMED OF SATELLITE

GOOD NEWS AT LAST
The surprise news that the US finally had a satellite in orbit briefly helped to calm the insecurity of the American public.

CELEBRATING SUCCESS
William Pickering, James Van Allen, and Wernher von Braun triumphantly display a full-sized model of Explorer 1 to a packed Washington press conference after the successful launch.



SATELLITE AND LAUNCH VEHICLE
The drum (with a vertical black stripe) linking Explorer 1 to the Redstone first stage contained two rings of Baby Sergeant rockets. The outer ring of 11 fired first, then the other three blasted free, carrying Explorer 1 into orbit.

JUNO BLASTS OFF
A pillar of fire shoots from the Redstone first stage as Explorer 1 begins its historic ascent into space. The Juno launcher seems short and stubby compared with the flawed elegance of Vanguard.

IN THE BLOCKHOUSE
Tense engineers monitor Explorer 1's progress under the supervision of Kurt Debus (left), director of the Launch Operations Center and another member of the V-2 team.

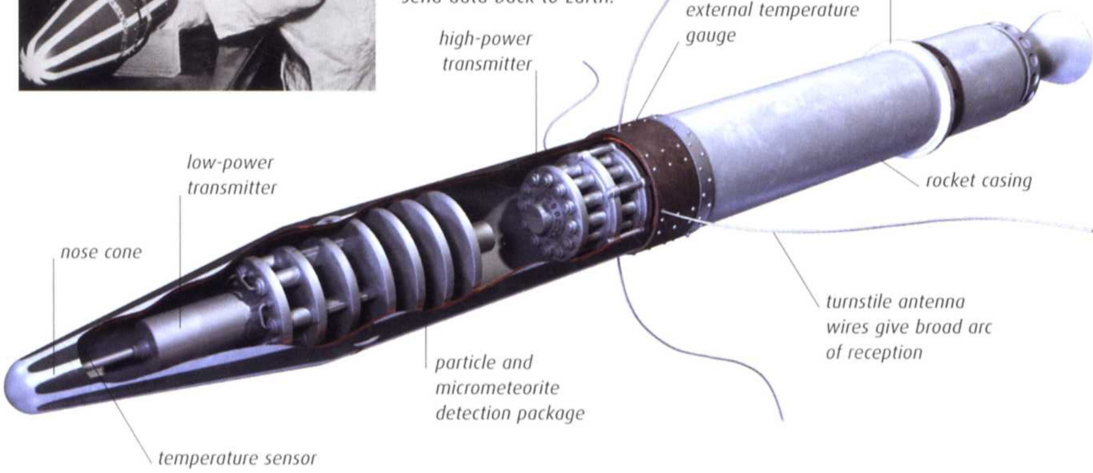
Sergeant solid-rocket missiles, allowing it to propel itself into orbit. Only the front half contained scientific instruments (see below). The satellite was linked to the lower-stage Jupiter C by a ring of modified Baby Sergeant rockets in a drum. These fired in two groups and separated in mid-flight, effectively acting as two intermediate stages. As in Vanguard, the upper stages were set spinning during launch and ascent in order to keep the vehicle stable.

Orbital Explorer

While the Vanguard team had to work under the pressure of a public deadline, preparations for Explorer 1 were mostly secret. The modified Jupiter C, renamed Juno to distance it from the military programme, was flown in to Cape Canaveral on 20 December, while the satellite joined it in late January 1958. Two launch attempts were abandoned, but high winds abated on 31 January, and Juno's main engines fired at 10:48pm local time. Despite the secrecy, thousands had gathered nearby to watch.

Von Braun, Pickering, and others saw the launch from the War Room at the Pentagon. As it turned out, Explorer 1 entered a higher orbit than expected, 2,520km (1,575 miles) from Earth at its highest point. This made it the most distant object launched so far, but the longer orbit also meant a delay before signals were picked up to confirm the satellite was safely in orbit. By the time von Braun, Pickering, and James Van Allen (see panel, below) arrived at the National Academy of Sciences for a news conference in the early hours of 1 February, the press had been alerted and they received a hero's welcome.

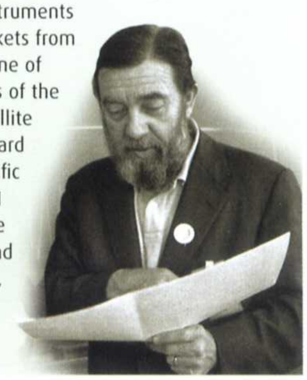
INSIDE EXPLORER 1
The rear of Explorer 1 was a miniature version of JPL's Sergeant rocket. The front contained three scientific instruments – a temperature sensor, a microphone system to detect the sound of tiny meteorites hitting the satellite, and the particle detector package (effectively an oversized Geiger counter). There was also a radio transmitter to send data back to Earth.



BIOGRAPHY

JAMES VAN ALLEN

William Pickering handed the task of designing Explorer 1's scientific instruments to James Van Allen (1914–2006), a scientist who had been investigating the upper atmosphere and near-Earth space since the 1940s. He had been involved in launching particle detectors and other instruments on V-2 and Bumper rockets from White Sands and was one of the strongest advocates of the project to launch a satellite during the IGY. The reward for his work was scientific immortality – Explorer 1 discovered the presence of radiation belts beyond the Earth's atmosphere, today known as the Van Allen Belts.



1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

15 May 1958
The launch of the Sputnik 3 orbiting laboratory emphasizes the power and dominance of Soviet launch vehicles.

18 December 1958
The experimental SCORE satellite is launched by an Atlas B rocket, broadcasting a pre-recorded message from President Eisenhower.

28 February 1959
The US launches an experimental spy satellite, Discoverer 1, intended to take photographs from space and then return a capsule of film safely to Earth.

11 August 1960
At the end of the Discoverer 13 mission, a film capsule is returned to Earth from orbit for the first time.

12 August 1960
NASA launches the experimental Echo 1 radio-reflector satellite.

4 October 1960
The US Army launches Courier 1B, the first satellite with the ability to receive and retransmit signals from the ground.

10 July 1962
Telstar, ancestor of the modern communications satellite, is launched. Television signals broadcast from space are received in the United States and Europe.

Early satellites

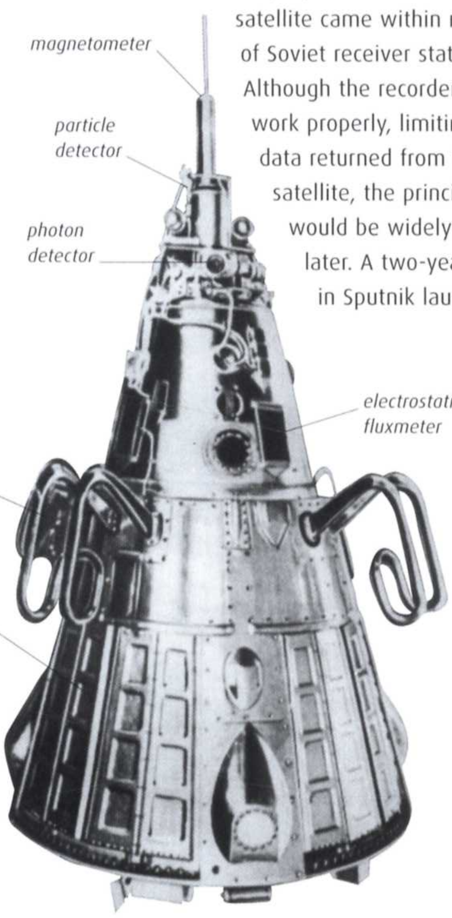
The opening exchanges of the Space Race were followed by a period of experimentation as both sides attempted to orbit increasingly ambitious satellites and establish the potential future uses of space.

The late 1950s and early 1960s saw many firsts: the first attempts at communication via satellite, the first attempts at Earth observation and using satellites for intelligence, and the first orbital laboratories.

Solar power

Although the Vanguard launcher was ultimately doomed by the more reliable Juno and its successors, it did achieve one significant milestone. On 17 March 1958, it successfully put the Vanguard TV-4 satellite into orbit. This small "grapefruit", identical to the one the US had failed to launch the previous December, was the first spacecraft that used solar cells to generate energy.

Tikhonravov's Object D satellite, a far more impressive use of solar power, finally made it to orbit as Sputnik 3 on 15 May 1958 (a failed launch in April meant that a backup was used). One of the craft's many innovations was a data recorder that would store instrument readings on magnetic tape and play them back when the satellite came within range of Soviet receiver stations. Although the recorder did not work properly, limiting the data returned from the satellite, the principle would be widely used later. A two-year hiatus in Sputnik launches followed, before they resumed in 1960 (later Sputniks were in fact tests for the manned Vostok missions).



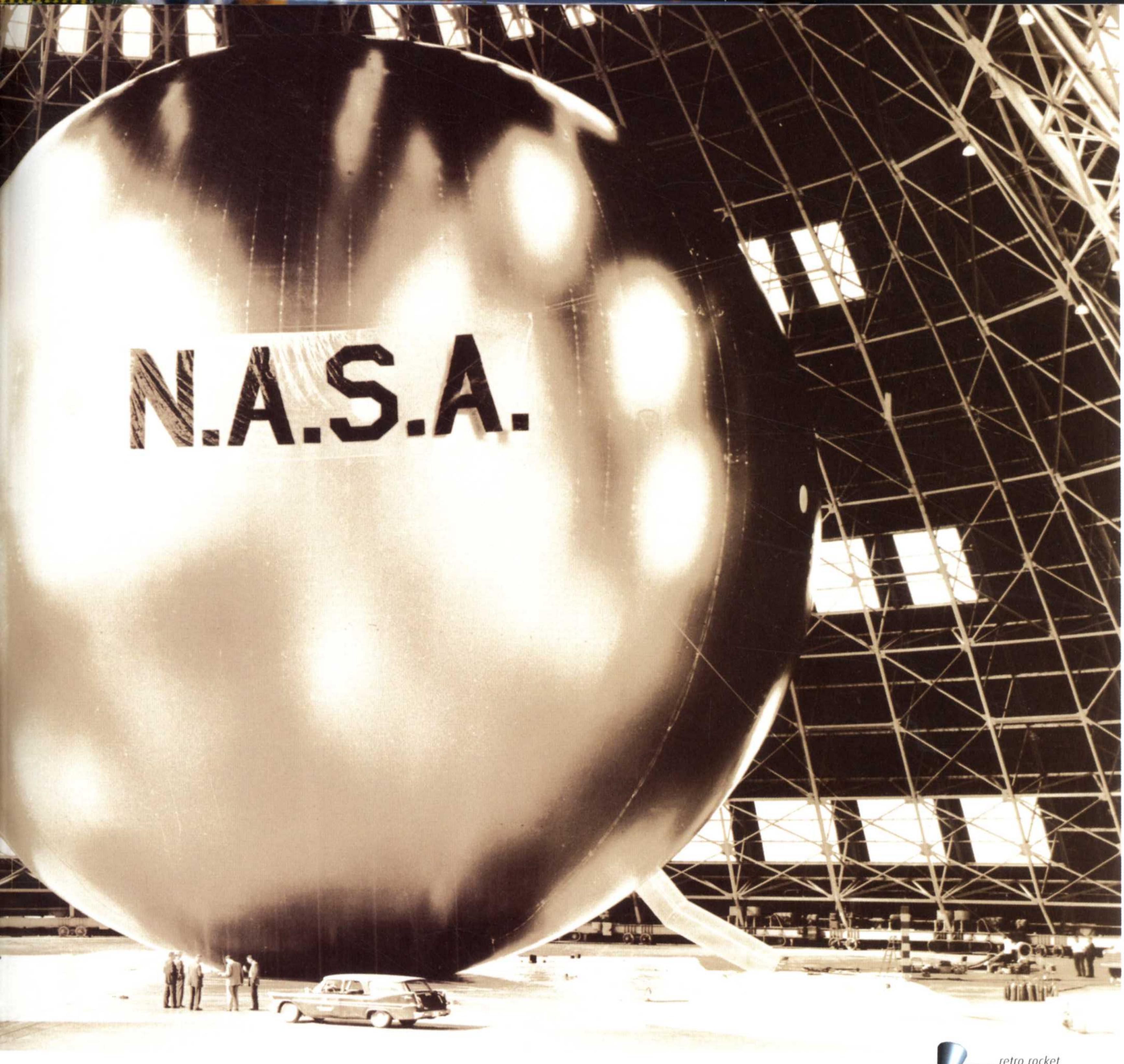
SPUTNIK 3
The third Sputnik to be launched weighed a massive 1,327kg (2,920lb) – far more than the US could hope to launch at the time. It carried a variety of instruments to study the environment around the Earth.

PROJECT ECHO
One of the earliest satellites launched by NASA, Echo 1 inflated after launch into a sphere 30m (100ft) across. When the satelloon, as it was called, was visible, signals bounced off it could be received at great distances.

Eyes in the sky

Since the US and Soviet space programmes were both driven by military priorities, the achievement of spaceflight was soon followed by the first attempts at surveillance. Space-based cameras would be less vulnerable to attack from the ground than spy planes (a point brought home when a US U-2 was shot down over the USSR in May 1960). Since the technology to send pictures back from space electronically was in its infancy (see p.52), the best way to capture high-resolution images was on photographic film that could then be returned to Earth. To test this, the US launched a series of Discoverer satellites (also known by the name Corona), of which Discoverer 13 was the first to return its film to Earth, dropping it into the atmosphere on 11 August 1960, to be retrieved in mid-descent by a C-119 transport plane. Meanwhile, the Samos programme experimented with electronic image transmission – developing its photographs in orbit before sending them back to Earth.

TRACKING THE SATELLITES
The arrival of the Space Age left the superpowers scrambling for ways of tracking their satellites around the globe. The first large radio telescope, at Jodrell Bank, England, found a new purpose tracking launches. Soon, the United States had installed tracking stations around the world, while the Soviet Union had equipped a fleet of tracking ships that could stay in contact with a spacecraft throughout its orbit.



Extraterrestrial relays

Communications was another area in which satellite technology needed proving. A large satellite in orbit could act as a reflector for radio signals (tested by the Echo project, which began in May 1960). A satellite could also broadcast a pre-recorded signal across a wide area (as with SCORE, which transmitted a Christmas message from President Eisenhower to the world in 1958). A more direct precursor of today's communication satellites was the US Army's Courier 1B, launched in October 1960. The world's first active repeater satellite, it recorded signals sent from the ground and then retransmitted them.

TECHNOLOGY

SATELLITE DESIGN

Getting complex machines to work in space requires a number of innovations. One of the worst problems is the temperature difference between sunlight and shade, which can cause components to expand, contract, and eventually fracture. Silvered insulation can help by deflecting much of the Sun's radiation, while highly conductive heat pipes can carry heat from hot areas to cooler ones. Delicate electronics must be cushioned with internal filling against the stress of launch and must also be robust enough to cope with flying through a blizzard of radiation and charged particles. Most satellites and probes also need stabilization and steering systems.

Pioneer 1

1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

17 August 1958
An unnamed US Air Force space probe intended to orbit the Moon is destroyed within two minutes of launch.

11 October 1958
Pioneer 1 fails to escape Earth orbit en route to the Moon.

2 January 1959
The Soviet Union launches Luna 1, also known as Mechta. It misses the Moon but becomes the first artificial object to leave Earth orbit.

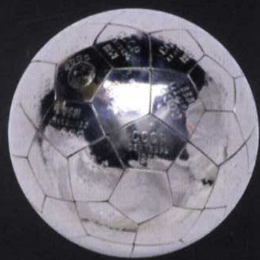
3 March 1959
Following three launch failures, Pioneer 4 escapes Earth orbit but misses its flyby of the Moon by 60,000km (36,000 miles) and does not return any data.

12 September 1959
Luna 2 is launched.

14 September 1959
Luna 2 crashes successfully into the Moon.

4 October 1959
Luna 3 is launched.

7 October 1959
Luna 3 travels behind the Moon and returns the first images of the lunar far side.



CARGO TO THE MOON
Both Luna 1 and Luna 2 carried a payload of small symbolic objects onboard, including "footballs" of pentagonal pennants designed to explode on impact and scatter their emblems over a wide area.

First to reach the Moon

The Earth's natural satellite, the Moon, sits on our cosmic doorstep and was an obvious first stop in the exploration of the Solar System. But in the 1950s, reaching it was still a major technological challenge.

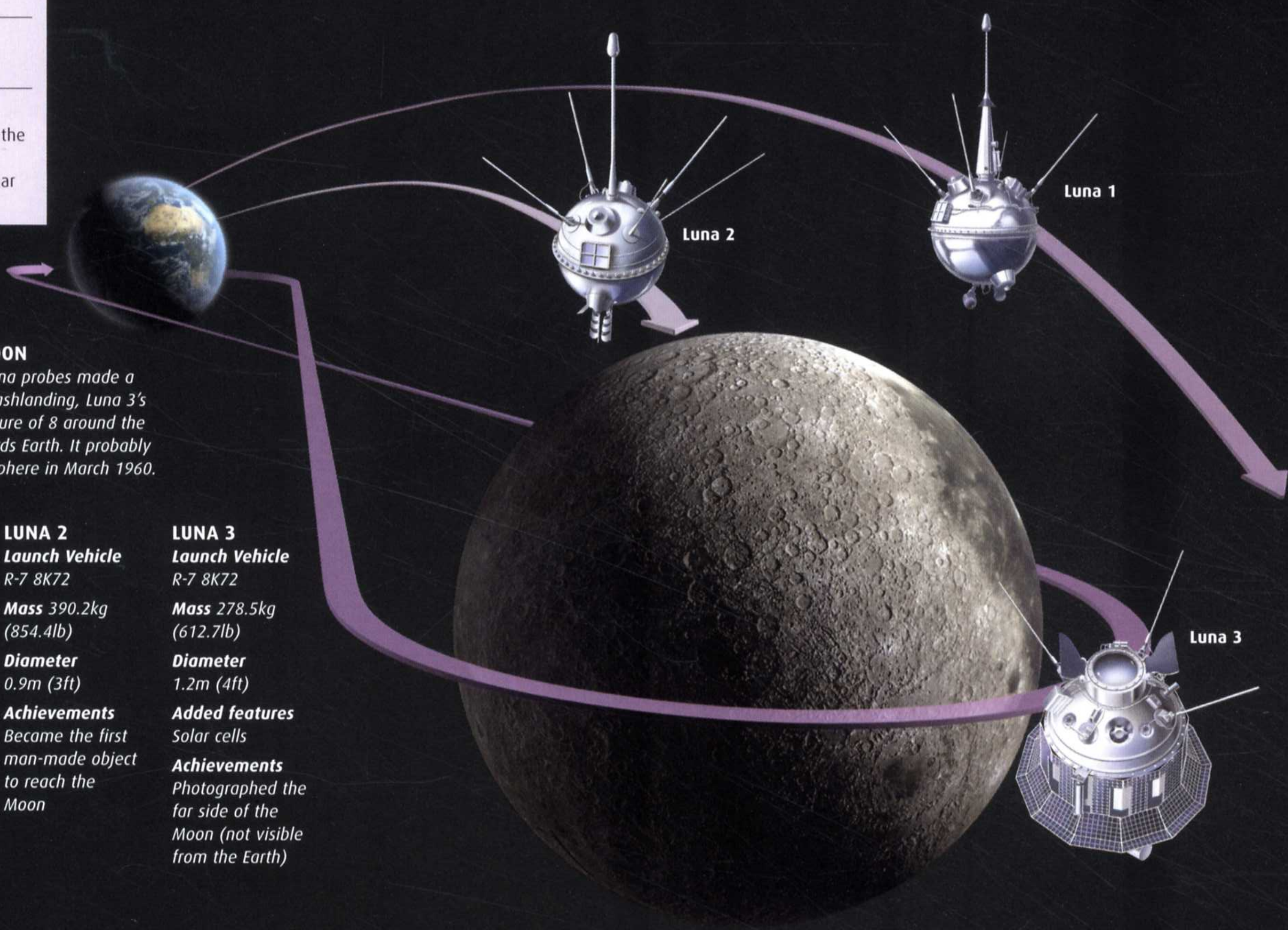
Considering the Soviet Union's clear lead in the Space Race at the start of 1958, it is somewhat surprising that history's first moonshots were in fact launched from Cape Canaveral. The first attempt, in August 1958, was part of the United States' programme for the IGY. It made use of a Thor Able-I rocket – the Air Force's new Thor IRBM with the second and third stages of a Navy Vanguard bolted on top of it. Unfortunately, the first stage failed just 77 seconds into the flight.

The following month, the newly formed NASA took over the lunar programme and immediately attempted a repeat of the earlier launch. This probe, named Pioneer 1, got a little further than its unnamed sibling, but a programming error meant that it still did not achieve sufficient speed to escape the Earth's gravity and reach the Moon – instead it arced 113,584km (70,549 miles) above the Earth before falling back to crash in the Pacific Ocean.

Further attempts at lofting a probe towards the Moon also met with failure. Pioneer 2 fell swiftly back to Earth when one of its rocket stages failed, and Pioneer 3, which used the Army's Juno II launch vehicle (a modified version of the finished Jupiter IRBM), suffered a similar fate. At least onboard radiation detectors on Pioneers 1 and 3 helped to define the extent of the Van Allen Belts.

The Lunik probes

The Soviet Union might have appeared inactive during these American launch attempts, but there was a lot going on in secret. The State Commission had approved a series of Moon probes in March 1958, but with little compromise on the size and

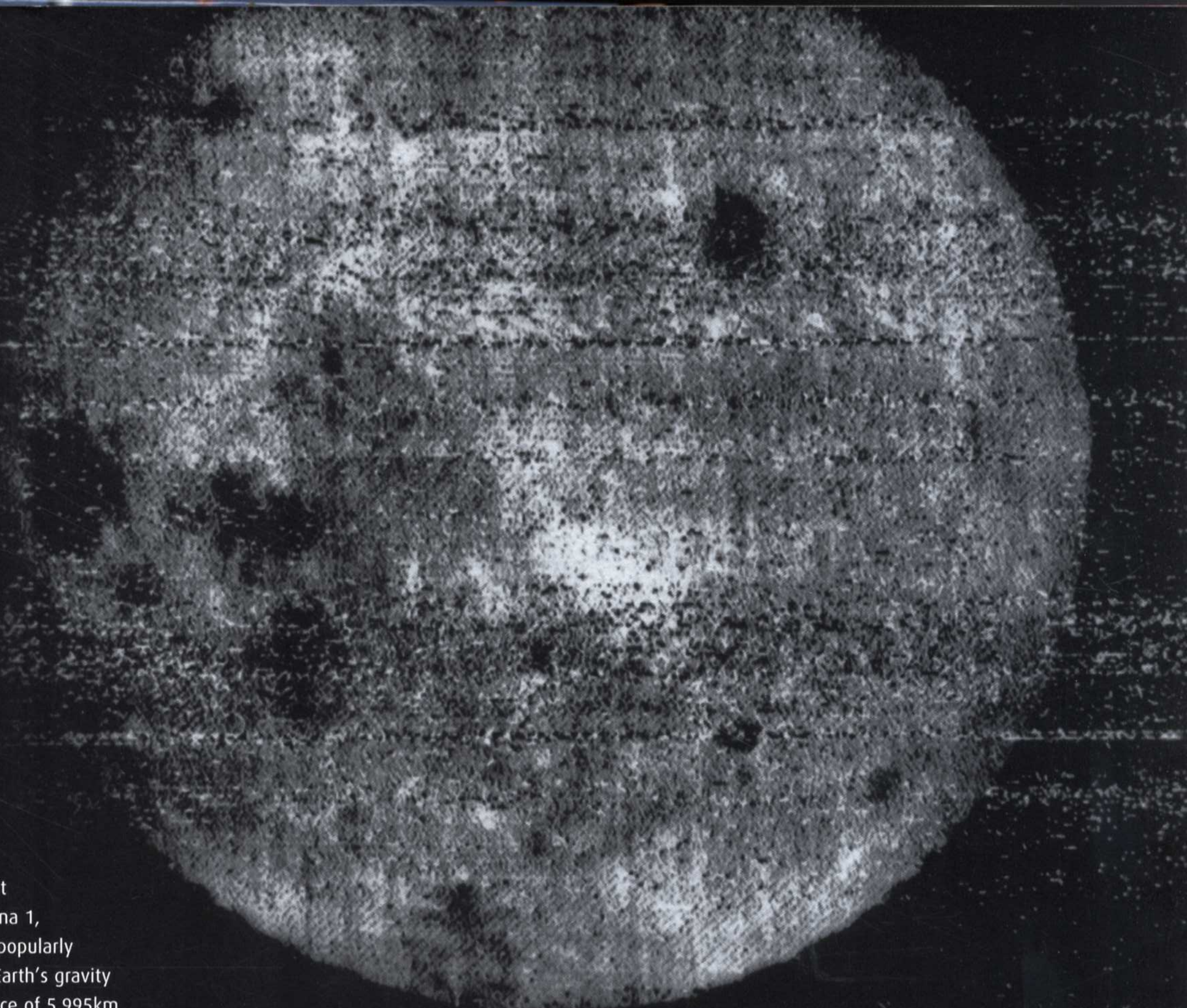


ROUTES TO THE MOON
While the first two Luna probes made a simple flyby and a crashlanding, Luna 3's orbit swung it in a figure of 8 around the Moon and back towards Earth. It probably re-entered the atmosphere in March 1960.

LUNA 1
Launch Vehicle
R-7 8K72
Mass *361kg (795.8lb)*
Diameter
0.9m (3ft)
Achievements
Failed to impact with the Moon but became the first spacecraft to fall into orbit around the Sun

LUNA 2
Launch Vehicle
R-7 8K72
Mass *390.2kg (854.4lb)*
Diameter
0.9m (3ft)
Achievements
Became the first man-made object to reach the Moon

LUNA 3
Launch Vehicle
R-7 8K72
Mass *278.5kg (612.7lb)*
Diameter
1.2m (4ft)
Added features
Solar cells
Achievements
Photographed the far side of the Moon (not visible from the Earth)



TO THE FAR SIDE
The Moon's far side is hidden from Earth because the Moon takes the same time to orbit the Earth as it does to spin on its own axis. The first images revealed a heavily cratered terrain.

weight of the new probes, a new upper stage would have to be fitted to the existing R-7 to propel its payloads towards the Moon. Launch attempts began on 23 September 1958 but the first three ended in explosions, and it was not until 2 January 1959 that Luna 1, also known as Mechta (Dream) and popularly nicknamed Lunik, broke free of the Earth's gravity and sailed past the Moon at a distance of 5,995km (3,723 miles), some 34 hours after launch. The spacecraft had been intended to crash directly into the Moon, but a control failure saw the mission change to a not-so-close flyby. However, the Soviet Union was still able to announce another triumph – and its achievement became all the more apparent in March, when Pioneer 4, the first semi-successful US moon probe, missed its target by 60,000km (36,000 miles) on its way into interplanetary space.

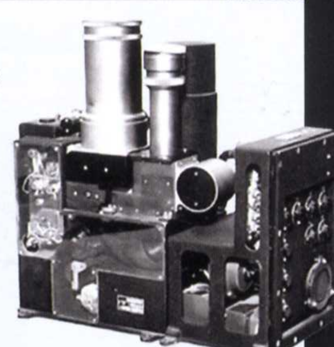
Throughout the remainder of 1959, the Soviets made the Moon their own. Despite further problems with the R-7 rocket, they successfully crashed Luna 2 into the Moon on 14 September. Venturing beyond the Van Allen Belts, this probe also discovered the solar wind – the stream of particles constantly blowing away from the Sun

One final coup for 1959 came on 7 October, when Luna 3 successfully swung past the Moon and used an ingenious electronic camera system (see panel, right) to send back the first images of the permanently hidden lunar far side.

UNDER CONSTRUCTION
The Luna probes were all manufactured at Korolev's OKB-1 design bureau. Luna 3, seen here, was the most complex of the early designs, incorporating a camera and additional solar cells to power it.

TECHNOLOGY

IMAGING THE MOON'S DARK SIDE



The Yenisey-2 "phototelevision" system carried onboard Luna 3 was the most sophisticated camera sent into space up to that time – a flying photo booth and fax machine combined. As the Moon's sunlit far side came into view, a light-sensitive cell triggered the exposure of its temperature- and radiation-resistant photographic film. These were automatically processed onboard, and once the probe was back in contact with Earth, a second radio command triggered the transmission system. This involved a cathode-ray tube that shone light through the film onto a photoelectric sensor that produced a signal proportionate to the transparency of the film. As the cathode-ray tube scanned back and forth across each picture, the varying signal sent back to Earth allowed the reconstruction of 17 low-resolution, but nevertheless ground-breaking, images of the mountainous far side of the Moon.

On to the planets

The next great targets for the racing space powers were the Earth's neighbouring planets, Venus and Mars – but they would soon learn that each presented its own unique challenges.

11 March 1960
Pioneer 5 becomes the first spacecraft deliberately launched into interplanetary space.

October 1960
Two attempted Soviet missions to Mars, timed to coincide with Soviet premier Nikita Khrushchev's visit to the United States, fail during launch.

4 February 1961
The first Soviet attempt to reach Venus fails to leave Earth orbit and is concealed with the codename Sputnik 7.

12 February 1961
Venera 1 is successfully launched toward Venus, but contact is lost after just a week.

22 July 1962
The Venus probe Mariner 1 fails when its Atlas-Agena B launch vehicle veers off course.

27 August 1962
Mariner 2 is successfully launched towards Venus.

1 November 1962
The Soviets finally launch a spaceprobe, Mars 1, toward Mars.

14 December 1962
Mariner 2 executes the first successful flyby of Venus.

21 March 1963
Mars 1 loses contact with Earth.

5 November 1963
Mariner 3 fails to escape Earth orbit.

2 April 1964
The Soviet Zond 1 probe is launched towards Venus but once again contact is lost during its journey.

28 November 1964
Mariner 4 is successfully launched toward Mars.

14 July 1965
Mariner 4 makes the first successful flyby of Mars.

The Soviet Union already had an advantage in this new heat of the Space Race – the same powerful launch vehicles that allowed it to put larger satellites into orbit also allowed it to launch smaller payloads further away from the Earth and, with the addition of extra rocket stages, out of Earth's gravity altogether.

Unlike orbital or even lunar launches, however, sending spacecraft to the planets relies on the calendar. As Venus, Earth, and Mars each orbit the Sun at a different rate, the distance between them is constantly changing, and the only practical period to launch a spaceprobe is around the time of their closest approaches to the Earth, typically within a brief launch window of perhaps just a few weeks.

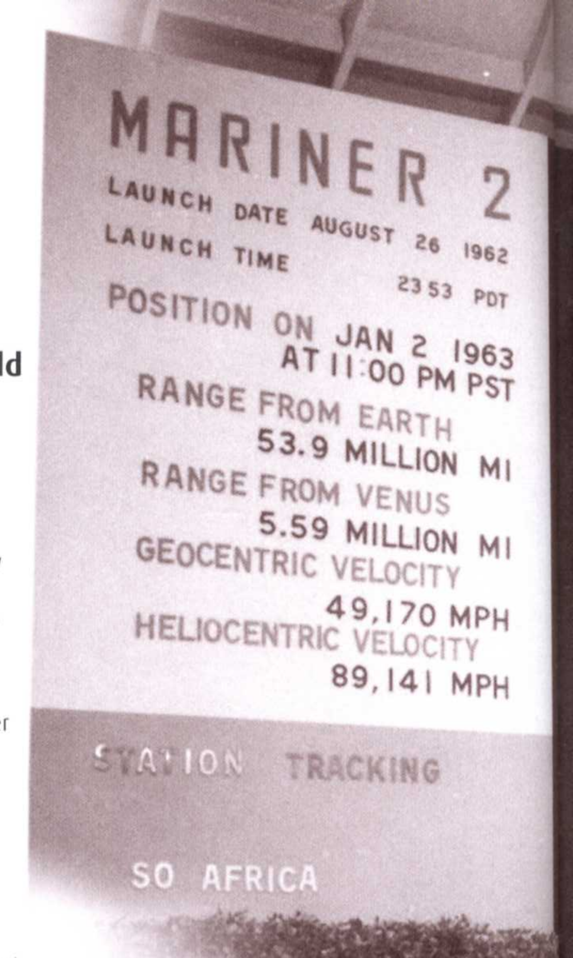
First attempts

Although both the US and USSR's first forays into interplanetary space had been accidental, the result of missed flybys of the Moon, the end of the 1950s saw NASA turn its Pioneer programme into a series of deliberate missions to investigate conditions away from Earth (see panel, opposite).

Meanwhile, Sergei Korolev was given approval to develop a series of planetary probes in late 1959, with the intention of sending a probe to Mars during the close approach late the following year. As the launch window approached, it became clear that it would coincide with a visit by Soviet premier Khrushchev to the United States – the ideal opportunity for another Soviet spectacular.

But for the first time, luck was against the Soviets – in mid-October 1960, two attempts to launch probes on a Martian flyby mission ended in rocket failures. These were hushed up, but rumours leaked out, along with tales of a third, disastrous rocket explosion that was for a long time seen as another failed attempt to reach Mars. Even though this probe was actually destined for Venus, the reality was rather different (see p.64).

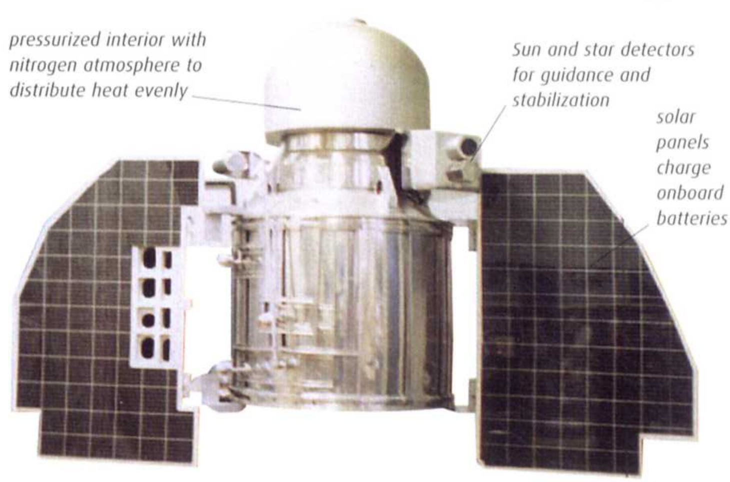
A few months later, around a close approach of Venus, the Soviets launched the first of their Venera probes. An initial failure was again covered up – it never left Earth orbit after its upper rocket stage failed – but the second attempt was on its way to Venus and trumpeted as another Soviet triumph when communications, embarrassingly, went dead.

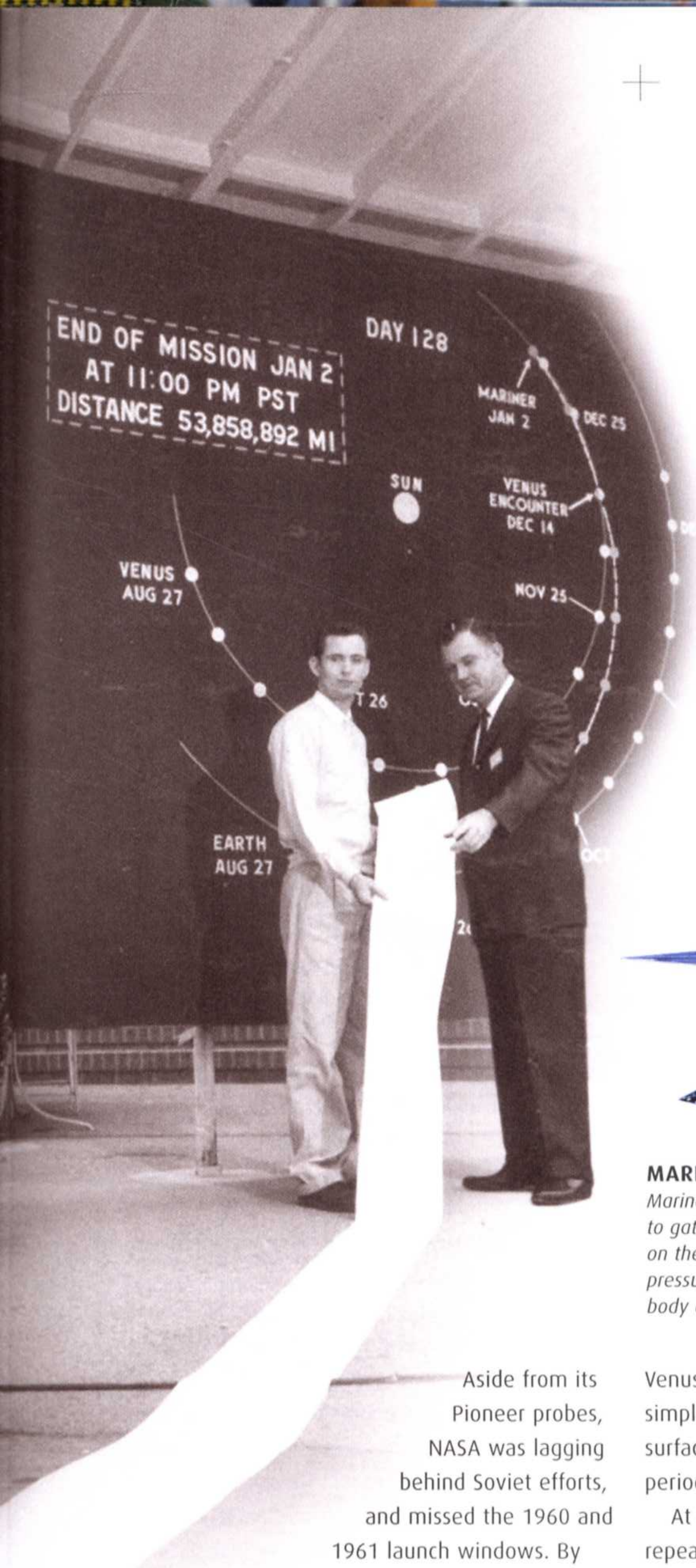


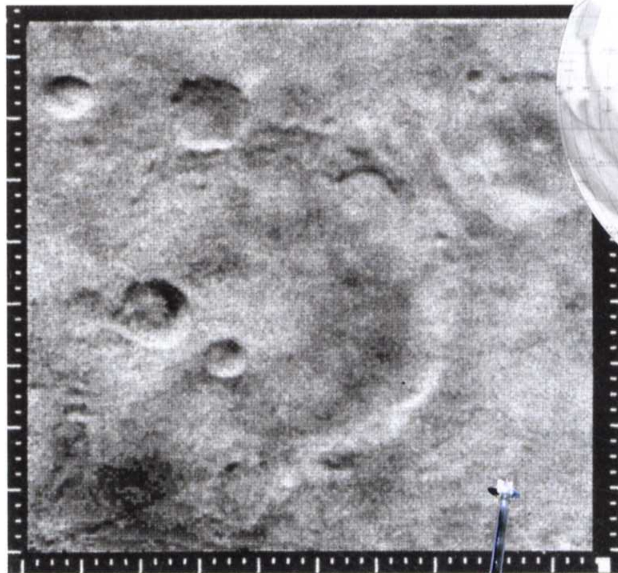
INCOMING DATA
Scientists at the Jet Propulsion Laboratory in Pasadena, builders of the Mariner probe series, pose with a stream of Venusian data in front of a chart showing Mariner 2's progress.

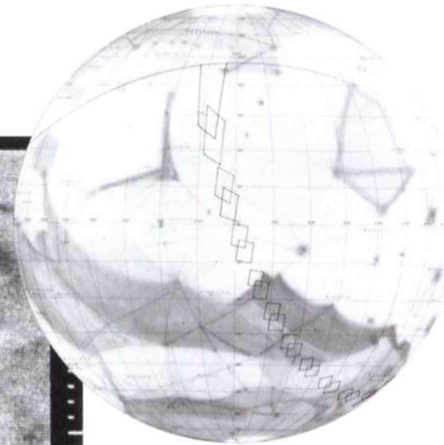
PLANETARY VISIONS
Until the 1960s, most people's ideas of other planets were inspired by the paintings of the visionary American artist Chesley Bonestell. His most famous work, Saturn Viewed From Titan, *is shown here.*

VENERA 1
Far more sophisticated than any previous space probe, Venera 1 stood 2m (6½ft) tall, weighed some 643.5kg (1,416lb), and incorporated a variety of scientific instruments.

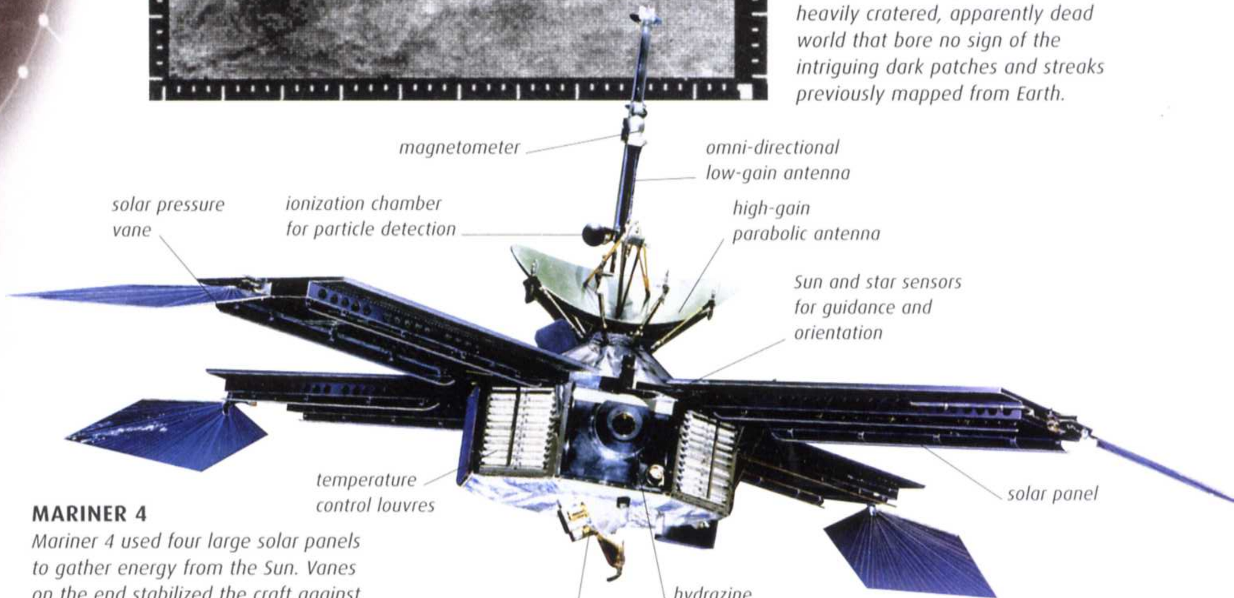








RED PLANET REVEALED
The images of Mars sent back by Mariner 4 proved to be a slight disappointment to some astronomers – they revealed a heavily cratered, apparently dead world that bore no sign of the intriguing dark patches and streaks previously mapped from Earth.



MARINER 4
Mariner 4 used four large solar panels to gather energy from the Sun. Vanes on the end stabilized the craft against pressure from the solar wind, and the body contained a variety of experiments.

Aside from its Pioneer probes, NASA was lagging behind Soviet efforts, and missed the 1960 and 1961 launch windows. By the following year, however, the Americans were ready to launch the first wave of their own armada to the planets – the Mariner probes. Both sides followed a deliberate policy of building probes in pairs so that two could be sent in the same launch window. But while the Soviets found this just doubled their failure rate, for NASA the story was "second time lucky".

So when Venus-bound Mariner 1 was destroyed after its launch vehicle (based on the Atlas ICBM) veered off course, Mariner 2 was ready to go in a matter of weeks – and this time, finally, everything went right for an interplanetary probe. Three-and-a-half months later, Mariner 2 made the first flyby of Venus and, although its instruments were relatively simple, it revealed that the planet has a baking surface, a dense, choking atmosphere, and a rotation period (243 Earth days) longer than its year.

At the next close approach of Mars, history repeated itself. Mariner 3 failed to leave Earth orbit after its protective shroud jammed, but on 28 November 1964, Mariner 4 launched perfectly. After a seven-month flight, the probe flew past Mars on 14 July 1965, coming within 10,000km (6,000 miles) of the Red Planet. It sent back 21 precious pictures of the surface and revealed that Mars lacks a magnetic field and had a much thinner atmosphere than expected.

Throughout the 1960s, the Mariner probes continued to deliver for NASA – Mariner 5 would fly past Venus in 1967, and Mariners 6 and 7 made close flybys of Mars in July and August 1969. The Soviets, meanwhile, had to endure a long learning curve before their Venera probes began to produce results (see p.260).

TECHNOLOGY

PROBING INTERPLANETARY SPACE

Less glamorous than the planetary probes, but just as scientifically important, were the Pioneer probes launched by NASA through the 1960s. The first were relatively simple probes that targeted the Moon (as shown here), but in March 1960 Pioneer 5 was deliberately sent into orbit around the Sun between the orbits of Earth and Venus. For the first time, this gave NASA experience in communicating with a spacecraft over interplanetary distances, and the probe paved the way for Pioneers 6 through 9. These more sophisticated probes, launched between December 1965 and November 1968, were designed to operate for up to 180 days each, but actually operated for years, allowing scientists to monitor conditions across the inner Solar System.

1961
The French CNES space agency is established.

26 April 1962
Ariel 1, a US-built satellite carrying British experiments, is launched.

1964
The British government approves development of the Black Arrow satellite launcher.

26 November 1965
France successfully launches the A-1 Astérix satellite, powered by a Diamant A rocket.

6 December 1965
A NASA Scout rocket launches the French FR 1 scientific satellite.

28 June 1969
The first test launch of Britain's Black Arrow ends in failure.

10 March 1970
Following development of the launch centre at Kourou, French Guiana, France launches the first Diamant B rocket.

29 July 1971
Britain announces the cancellation of Black Arrow.

28 October 1971
The last flight of Black Arrow successfully orbits Britain's Prospero satellite.

4 April 1972
A Soviet rocket launches the French-built SRET satellite.

Britain and France in space

As the Space Race between the superpowers gathered pace, other countries began to recognize the importance of an independent launch capability. First among these were Britain and France, but the two space programmes would develop in very different directions.

Britain and France both inherited small parts of the German V-2 legacy at the end of the Second World War, and enthusiastic engineers (many of whom had started out in rocket societies) were soon at work replicating and learning from the technology. As with the superpower space programmes, these projects were staffed by space enthusiasts, even if they were driven by military priorities.

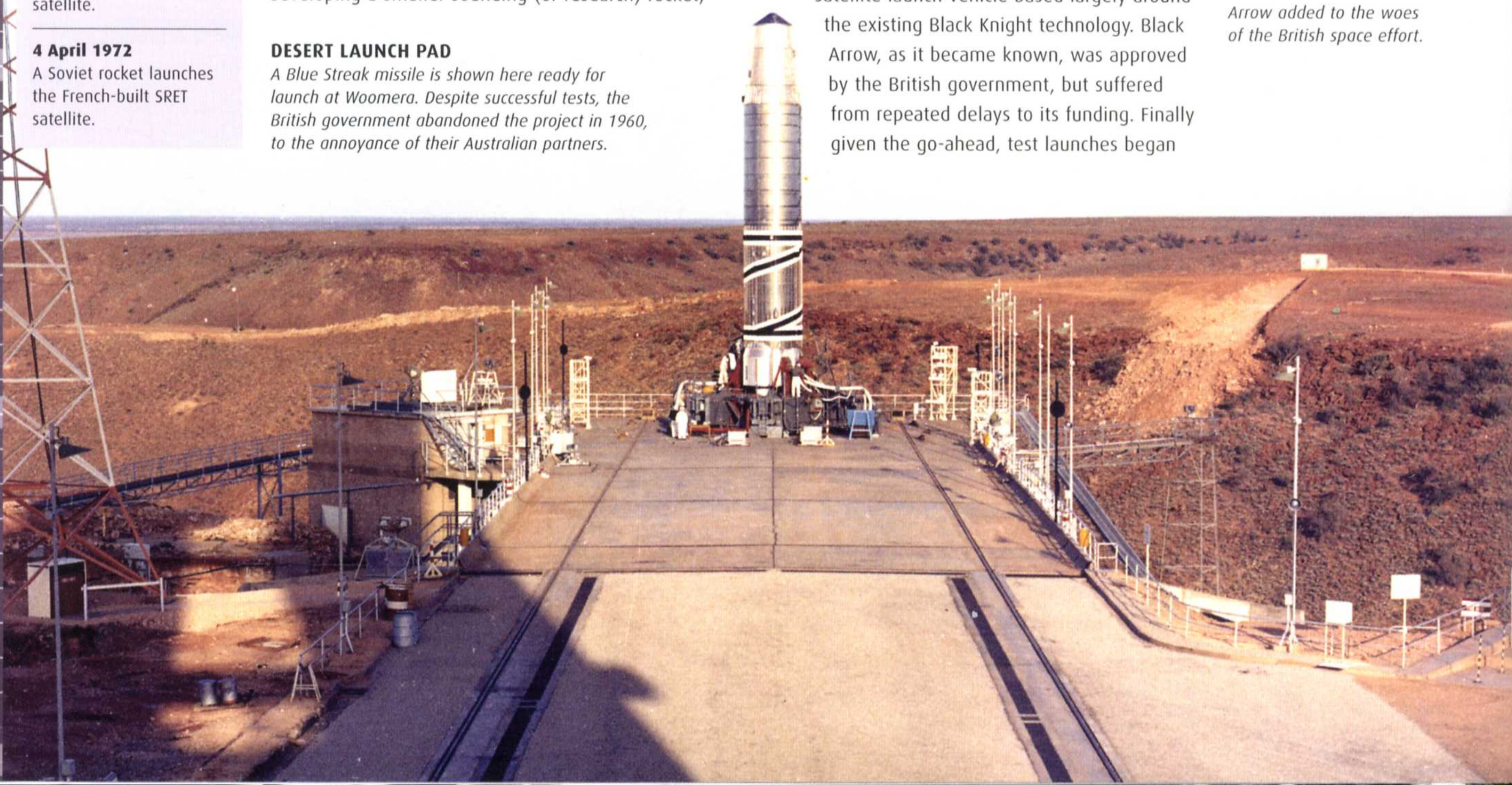
Hopes unfunded

In 1954, Britain began work on its own intermediate-range ballistic missile, the Blue Streak, with assistance from Australia (Woomera in the Australian outback was to be used as a testing range). Despite early successful tests, spiralling costs and doubts about Blue Streak's military effectiveness eventually led to the cancellation of the programme in 1960.

But Blue Streak lived on in other forms for another decade. Britain at first tried to interest Canada and Australia in a collaboration to build a three-stage launch vehicle called Black Prince, with Blue Streak as its first stage. When no deal could be reached, the missile became a crucial element in the ill-fated European ELDO project (see p.229). In parallel with Blue Streak, Britain had also been developing a smaller sounding (or research) rocket, Black Knight – initially to test warhead designs for use on Blue Streak. Uniquely, Black Knight utilized high test peroxide (HTP), a concentrated form of hydrogen peroxide, as an oxidizer. First used in some German experimental rocket engines, HTP's violently combustible nature allowed the design of Black Knight's Gamma engines to be greatly simplified.

By the 1960s, Britain led the world in HTP propulsion, and in 1964 the Royal Aircraft Establishment proposed building a small, cheap satellite launch vehicle based largely around the existing Black Knight technology. Black Arrow, as it became known, was approved by the British government, but suffered from repeated delays to its funding. Finally given the go-ahead, test launches began

AUSTRALIA-BOUND
Although the Blue Streak missiles were manufactured in Britain, the lack of a suitable launch site meant that they had to be shipped around the world from the Spadeadam Rocket Establishment in Cumbria (shown here) to the Australian missile range at Woomera for testing. Transport delays to both Blue Streak and Black Arrow added to the woes of the British space effort.



DESERT LAUNCH PAD
A Blue Streak missile is shown here ready for launch at Woomera. Despite successful tests, the British government abandoned the project in 1960, to the annoyance of their Australian partners.

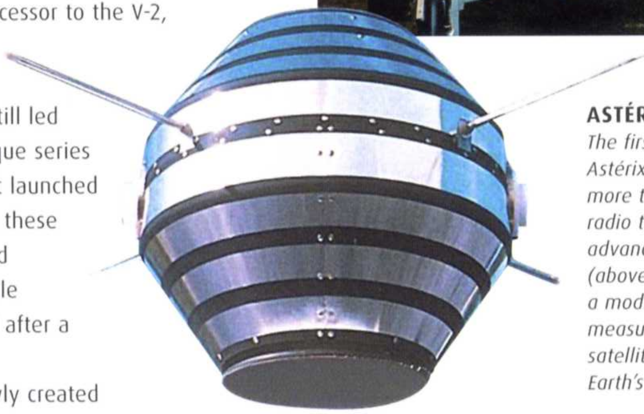
in 1969, but a troubled start to the programme meant that, with astounding lack of foresight, the government cancelled the project in July 1971, on the eve of its greatest success (see panel, below). In the future, it seemed, Britain would be content to rely on small American rockets to launch its satellites. But soon British satellites themselves would be a thing of the past, and from the 1970s, Britain's space effort would generally extend no further than its limited involvement in the new European Space Agency, ESA.

France enters space

While Britain's rocket programme ultimately failed due to a lack of political vision, the French effort thrived on Gallic self-assurance. In the late 1940s, French scientists, helped by a few of their captured German counterparts, formed plans to turn the A9, von Braun's planned successor to the V-2, into reality. While these ideas proved overly ambitious, they still led to the successful Veronique series of sounding rockets, first launched in 1950. In parallel with these efforts, France developed a series of ballistic missile prototypes, each named after a precious stone.

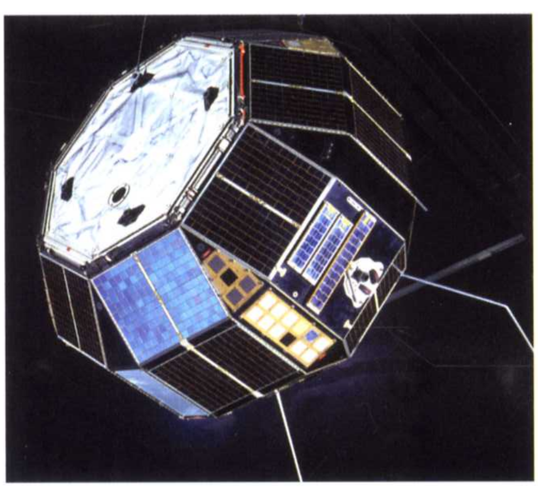
In 1961, France's newly created space agency, the Centre National d'Etudes Spatiales (CNES), decided to build a satellite launch vehicle. Diamant, as it became known, was evolutionary rather than revolutionary – a tried and tested two-stage Saphir missile with a new third stage added. The first Diamant A launch took place at Hammaguir, Algeria, in November 1965 and was an unqualified success, launching a small satellite, the A-1 or Astérix, into orbit. This made France only the third nation on Earth to launch its own satellite.

Diamant launches continued alongside French involvement in the ELDO project, but in the late 1960s France also developed the improved Diamant B launcher and a new launch complex at Kourou in French Guiana. Diamant B first launched from Kourou in March 1970, and the programme continued until 1975. When France ultimately abandoned its national launch vehicle, it was only to take the lead role in ESA's more ambitious Ariane project.



ASTÉRIX AND DIAPASON
The first French satellite, Astérix (left), was little more than an orbiting radio transmitter. More advanced was Diapason (above), which incorporated a modified transmitter for measuring the speed of the satellite and therefore the Earth's varying gravity.

DESERT LIFT-OFF
A Diamant A rocket blasts off from the original French launch site at Hammaguir in the Algerian desert in 1965.



THE ARIEL SERIES
Britain's first satellites were the Ariel series, launched by NASA on Delta and solid-fuelled Scout rockets between 1962 and 1979. Ariels 1 and 2 were built in the US and fitted with British experiments, while Ariels 3 and 4 were entirely British-built. Each studied galactic radio signals and the properties of the Earth's ionosphere. The later Ariels 5 and 6, in contrast, were two of the earliest X-ray astronomy satellites.

HISTORY FOCUS

BRITAIN'S SPACE SWANSONG

The first Black Arrow test flight in June 1969, codenamed R0, veered off course due to a steering problem, but a successful second test eight months later (right) cleared the way for a satellite launch attempt in September 1970. Unfortunately this R2 launch failed to reach orbit when the second stage shut down early. Despite the project's cancellation in July 1971, permission was given to launch the R3 vehicle. With just one chance to get it right, the launch slipped to late 1971, but this time everything went perfectly, and the Prospero satellite entered orbit on 28 October 1971. Despite this, there was to be no reprieve, and Britain gained the distinction of being the first country to abandon its satellite launch capability.

The birth of Vostok

With their lead in the Space Race now established, the Soviet engineers turned their attention to the next great challenge – developing a vehicle suitable for manned spaceflight.

Although Mikhail Tikhonravov had first sketched out plans for manned spacecraft in the late 1940s, it was not until the mid-1950s that the Council of Chief Designers began to discuss the idea seriously. By 1955, some five different spacecraft designs were under consideration, and proposals for a series of suborbital spaceflights launched with the R-5 rocket got as far as recruiting volunteer cosmonauts, before being shelved as work on the R-7 ICBM took priority.

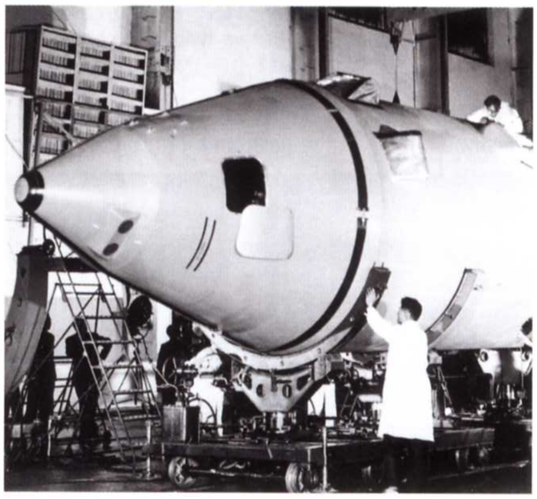
Off the drawing board

In early 1957, with plans for the first satellite launch well under way, Korolev created a new planning group at OKB-1, where talented young engineers would work on designs for a manned spacecraft that could be launched with the R-7. The kindergarten group, as it was known, developed a proposal for a two-element spacecraft, with a spherical Descent Module attached to the front of a conical Instrument Module, similar in design to Tikhonravov's Object D satellite (Sputnik 3). The Instrument Module would be abandoned in orbit, and the cosmonaut would stay seated in the Descent Module throughout the flight, ejecting and parachuting to the ground at the last moment.

Originally known as Object OD-2, the spacecraft was soon given the more evocative name of Vostok (East). By the time Korolev gave it his seal of approval in June 1958, the design had evolved, with plans for both manned and unmanned versions (in the unmanned version, later known as Zenit, the Descent Module would carry reconnaissance equipment). In May 1959, after some fierce political wrangles over which element of the programme took priority, the State Commission finally authorised a production schedule that aimed to achieve the first manned spaceflight by late 1960.

Fate had other ideas, however – test launches got going in May 1960, but after a series of setbacks to other aspects of the space programme in late 1960 (see pp.54, 64–65) it was to be the spring of 1961 before Korolev was allowed to risk a manned launch.

LIFTING FOR LAUNCH
Like all rockets launched at Tyuratam, the R-7s were transported horizontally along a purpose-built railway system and raised to point skywards at the launch pad.



IN PRODUCTION
The production-line system established for the Vostok capsules has remained largely unchanged to this day. Here engineers work on fitting a Vostok spacecraft into its launch shroud.

TECHNOLOGY

BAIKONUR COSMODROME

The main Soviet launch centre, the Baikonur Cosmodrome, was actually located near the village of Tyuratam, 370km (230 miles) from the town of Baikonur – the facility's location was deliberately misrepresented in an effort to confuse Western intelligence. Construction got under way in mid-1955 at a frenetic pace – a small army of construction workers and engineers was transported to a remote site in the deserts of Kazakhstan (then a Soviet Republic), where they developed facilities for the preparation and launch of rockets. Meanwhile, the railway from Tyuratam itself was improved and extended to carry rockets and other equipment transported from the factories and design bureaux around Moscow.

19 May 1960
The first unmanned test flight of the Vostok capsule, disguised as Sputnik 4, becomes stranded in orbit.

19 August 1960
A second Vostok test, Sputnik 5, carries dogs Strelka and Belka into space and successfully returns them to Earth after a day in orbit.

1 December 1960
Sputnik 6 is launched into orbit but burns up on re-entry the next day.

9 March 1961
Sputnik 9, carrying a dummy cosmonaut and a dog named Chernushka, makes a successful test flight.

25 March 1961
Another successful test flight, this time under the name Sputnik 10, clears the way for a manned launch by the Soviets.

STAR OF THE EAST
Sited in central Kazakhstan, well away from foreign borders, the Tyuratam launch site covers an area of 6,721 square km (2,593 square miles). A further 104,279 square km (40,262 square miles) of land downrange of the launch facilities was cleared in case of any rocket failures.

1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

August 1959
Cosmonaut selection teams visit air bases throughout the Soviet Union, searching for candidate astronauts among their top pilots.

March 1960
Construction work begins on the training complex at Star City.

11 June 1960
The cosmonaut training centre at Star City is established. Korolev has already chosen his shortlist of candidate Vostok pilots.

18 June 1960
The 20 successful cosmonaut candidates visit Kaliningrad to see the Vostok capsule under development.

19 September 1960
Korolev submits a formal proposal for a manned spaceflight for official approval by the Communist Party's Central Committee.

6 January 1961
A shortlist of six candidates for the first manned Vostok flight is drawn up.

March 1961
Gherman Titov and Yuri Gagarin are selected as the two potential pilots for Vostok 1.

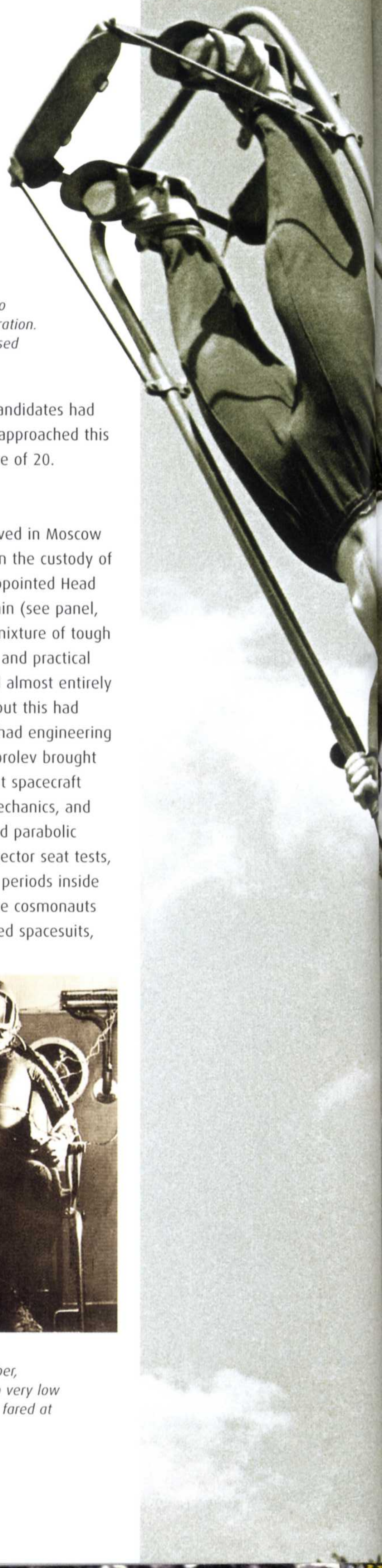
Cosmonaut training

With the development of a manned Soviet space capsule finally approved in May 1959, the search for suitable cosmonauts could finally get underway.

Although the formal search for cosmonaut candidates did not begin until late 1959, there had already been some discussion of the qualities needed in a good cosmonaut, and, just as in the United States (see p.70), the selectors soon realised that jet pilots were most likely to meet the basic requirements.

In August 1959, a group of experts in aeronautical medicine began visiting air bases across the Soviet Union and interviewing candidates to fly what they mysteriously described as a "completely new type of aircraft". It was established whether the pilots had any interest in space travel, though other important selection criteria were as mundane as height and weight – many were rejected simply because they were too tall or too heavy.

Out of about 3,000 interviewees, the selection panel drew up a list of 102 potential cosmonauts, who were then sent for intensive and sometimes harrowing medical testing. Aside from numerous X-rays and physiological tests, the experts assessed their psychological well-being and ability to cope with stress and isolation. The most difficult challenge was the isolation chamber, where candidates would live and work for several days at a time, subjected to a cycle of day and night determined at the whim of the operators, with long periods of silence punctuated by occasional deafening noise. By the end of this process, the shortlist of candidates had dwindled to 40, but as the deadline approached this was further reduced to an initial wave of 20.



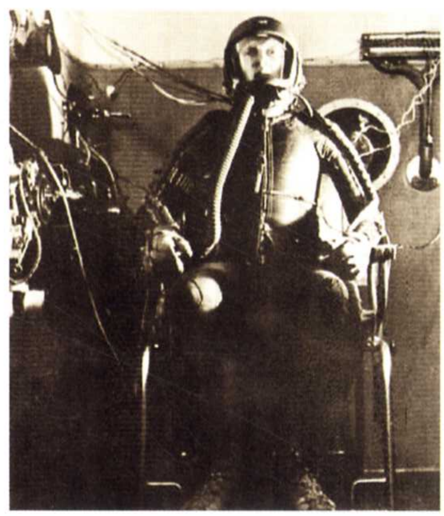
CRUDE BUT EFFECTIVE
Gherman Titov spins on apparatus used to familiarise cosmonauts with rapid acceleration. The Soviet cosmonaut programme also used rapidly spinning centrifuges for training.

Into training

When the candidate cosmonauts arrived in Moscow for training, they found themselves in the custody of an intimidating figure – the newly appointed Head of Cosmonaut Training Nikolai Kamanin (see panel, opposite). Kamanin's regime was a mixture of tough physical exercise, academic lectures, and practical training. At first, the lectures focused almost entirely on the biomedical aspects of flight, but this had little appeal for a group that mostly had engineering backgrounds, and so Kamanin and Korolev brought in engineers from OKB-1 to talk about spacecraft and launch-vehicle design, orbital mechanics, and astronomy. Training exercises included parabolic flights to simulate weightlessness, ejector seat tests, countless parachute jumps, and long periods inside the isolation chamber. In addition, the cosmonauts had to get used to the newly designed spacesuits,

SUITING UP
A trainee is fitted with the underlayers of his spacesuit. Soviet suits were developed from those used in high-altitude balloon flights.

WIRED FOR TESTS
Gherman Titov concentrates during medical tests – trainees were often subjected to violent vibrations or extremes of temperature.



UNDER PRESSURE
In the altitude pressure chamber, cosmonauts were subjected to very low air pressures to test how they fared at high altitude.

FIRST COSMONAUTS
A rare group photograph captures the first nine Soviet spacefarers at Star City in 1964. At rear, left to right, are the Sputnik cosmonauts Bykovsky, Titov, Gagarin, Nikolayev, and Popovich. In front are Boris Yegorov, Konstantin Feoktistov, and Vladimir Komarov (the crew of Voskhod 1), along with Valentina Tereshkova.

modified from high-altitude pressure suits, which they would have to wear throughout the flight. At first the trainees were based at a Moscow airfield, but by June new accommodation was ready at the specially built town of Zvezdny Gorodok (Star City), just outside Moscow. The new facilities included a flight simulator for the Vostok spacecraft itself, but with equipment limited it was decided to focus on an even smaller number of cosmonauts.

The lucky members of this "group for immediate preparedness", named on 30 May 1960, were Yuri Gagarin, Anatoly Kartashov, Andrian Nikolayev, Pavel Popovich, Gherman Titov, and Valentin Varlamov. Kartashov and Varlamov were invalided out after accidents, to be replaced by Valery Bykovsky and Grigori Nelyubov. Gagarin and Titov soon emerged as Korolev's favourites – though he took to the entire group and called them "my little swallows".

Delays and setbacks

Even as the cosmonauts were training and the Vostok capsules rolling off the production line, rows continued about whether and when a manned launch should go ahead. The military continued to lobby for concentration on the unmanned Vostok-based spy satellites at the expense of what they saw as the publicity stunt of human spaceflight.

Meanwhile, two early attempts to launch a Mars probe failed (see pp.54–55) and a third ended in the disaster known as the Nedelin catastrophe (see p.66). There was also concern about the biological effects of spaceflight after Belka, one of two dogs carried aboard Sputnik 5, was sick in orbit.

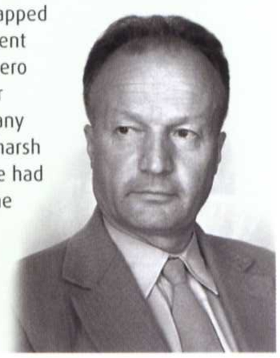
Contrary to rumours spread in the West about Soviet recklessness, Khrushchev and his engineers were very unwilling to risk a cosmonaut until they could expect to get him back in one piece.

With a manned launch planned for the spring of 1961, there was one further tragic setback to come. On 23 March, the youngest of the trainees, 24-year-old Valentin Bondarenko, died when a fire broke out in the oxygen-rich atmosphere of the isolation chamber. It was just days before the expected launch window opened, and the leading cosmonauts were not immediately told what had happened. A week later, on 30 March, final authorization for a launch was agreed.

BIOGRAPHY

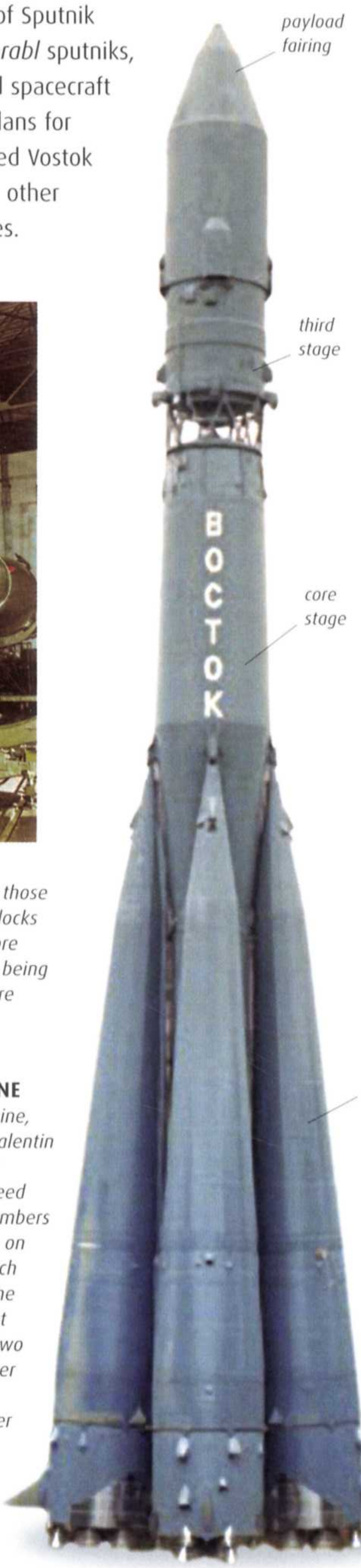
NIKOLAI KAMANIN

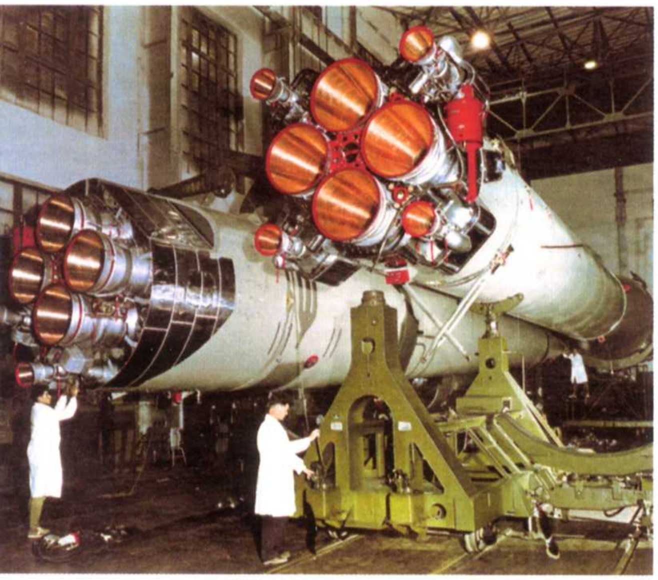
General Nikolai Kamanin (1908–82) was a highly respected and formidable figure when made Head of Cosmonaut Training in 1960 (a role he held until 1971). After training as a pilot and an early career as a polar explorer, he became famous in 1934 for his role in the rescue of passengers and crew from an ice-bound steamship trapped in the Arctic Ocean – an event which saw him named a Hero of the Soviet Union. At Star City, he was disliked by many of the cosmonauts for his harsh regime and manner, but he had some progressive ideas – he was keen to train a group of women for space, and supported calls for civilian cosmonauts.



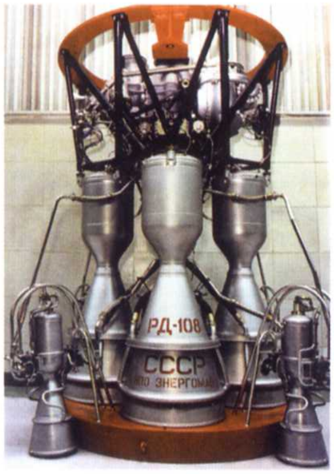
Vostok spacecraft

Designed by Mikhail Tikhonravov's "kindergarten" team, the first manned spacecraft combined a spherical manned Descent Module with an unmanned Instrument Module and retrorocket unit. Unmanned versions were flown under cover of Sputnik launches 4 onwards (sometimes known as *korabl* sputniks, from the Russian for "ship"), and the manned spacecraft was launched half-a-dozen times. Although plans for later manned flights were scrapped, unmanned Vostok variants carrying reconnaissance cameras and other experiments continued to fly for three decades.





THE VOSTOK ROCKET
The lower stages of the Vostok rocket were identical to those of the reliable R-7 Semyorka rocket, with four engine blocks powered by an RD-107 engine, surrounding a central core powered by the RD-108. Here, one of the side blocks is being attached to the core during assembly. Both engines were powered by kerosene and liquid oxygen.

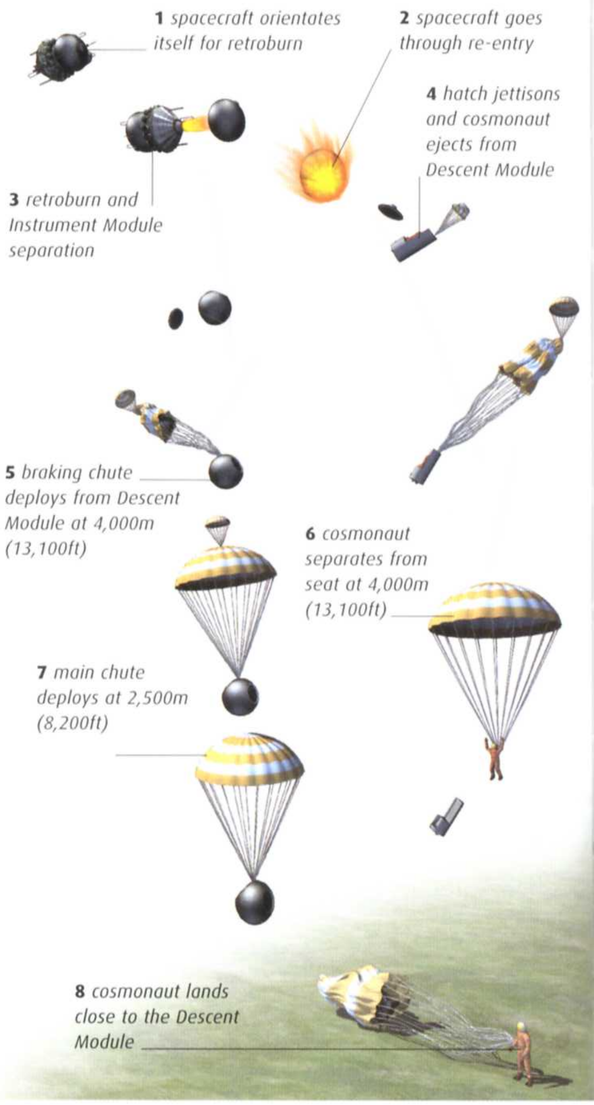


RD-107 ENGINE
The RD-107 engine, developed by Valentin Glushko, used a turbopump to feed combustion chambers similar to those on the V-2. Four such chambers fed the four main rocket nozzles, while two gimballed vernier engines on the side helped steer the rocket.

VOSTOK ROCKET
The 8K72K launch vehicle developed for Vostok used the lower stages of an R-7 with a 3m (10ft) third-stage engine similar to that used to boost the early Luna probes.

BLAST-OFF FROM BAIKONUR
Support gantries fall away from each side of a Vostok rocket as it blasts its way into the sky. Flames from the exhaust are directed into the pit below, where they escape along tunnels so they cannot threaten the rocket.

RE-ENTRY AND LANDING SEQUENCE
Dropping the Vostok spacecraft out of orbit required turning it around in space so it was facing backwards. Once the retrorockets had fired, the Instrument Module separated and the Descent Module plunged towards Earth. After re-entry, the cosmonaut ejected from the Descent Module and parachuted to the ground separately. The Instrument Module continued in orbit.



INSIDE THE SPACESHIP
The interior of the Descent Module was heavily padded. A small window in the front allowed the cosmonaut to see out, and, with the bulky ejector seat in place, there was just enough room for the later Vostok cosmonauts to release their harness and float free.

VOSTOK CONTROL PANEL
The Vostok controls were in two sections, of which this is the main one. In total, there were just four switches and 35 indicators – plus a hand controller for use only in emergencies.

DESCENT AND INSTRUMENT MODULES
The spherical Vostok Descent Module was weighted so that it tilted to re-enter the atmosphere with its heat shield leading the way. The Instrument Module was based on Tikhonravov's Object D satellite (flown as Sputnik 3).

CREW	1
LENGTH	4.4m (14ft 5in)
MAXIMUM DIAMETER	2.43m (7ft 11in)
MASS AT LAUNCH	4,730kg (10,420lb)
MASS AT LANDING	2,460kg (5,412lb)
ENGINES	Nitrous oxide/amine
MANUFACTURER	Korolev/OKB-1

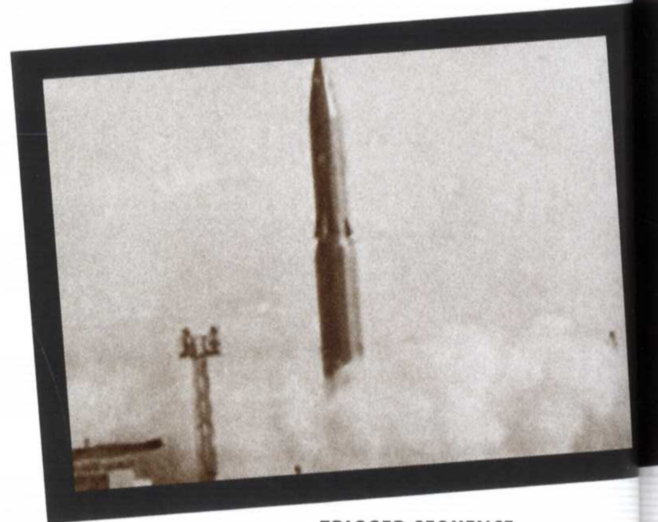
EXPERIENCE

DISASTER ON THE LAUNCH PAD

MITROFAN NEDELIN
After a proud military career that saw him fight against the fascists in the Spanish Civil War and command artillery in the Ukraine, all that remained to identify Marshal Nedelin was his gold star as a Hero of the Soviet Union.

The Nedelin catastrophe

The explosion that rocked Baikonur Cosmodrome on 24 October 1960 was the greatest disaster in the history of rocketry, taking the lives of 126 Soviet space and missile personnel.



TRIGGER SEQUENCE
Cameras designed to trigger when the missile's engines fired captured the explosion and its horrific aftermath frame by frame. By the end, only charred wreckage of the R-16 remained.

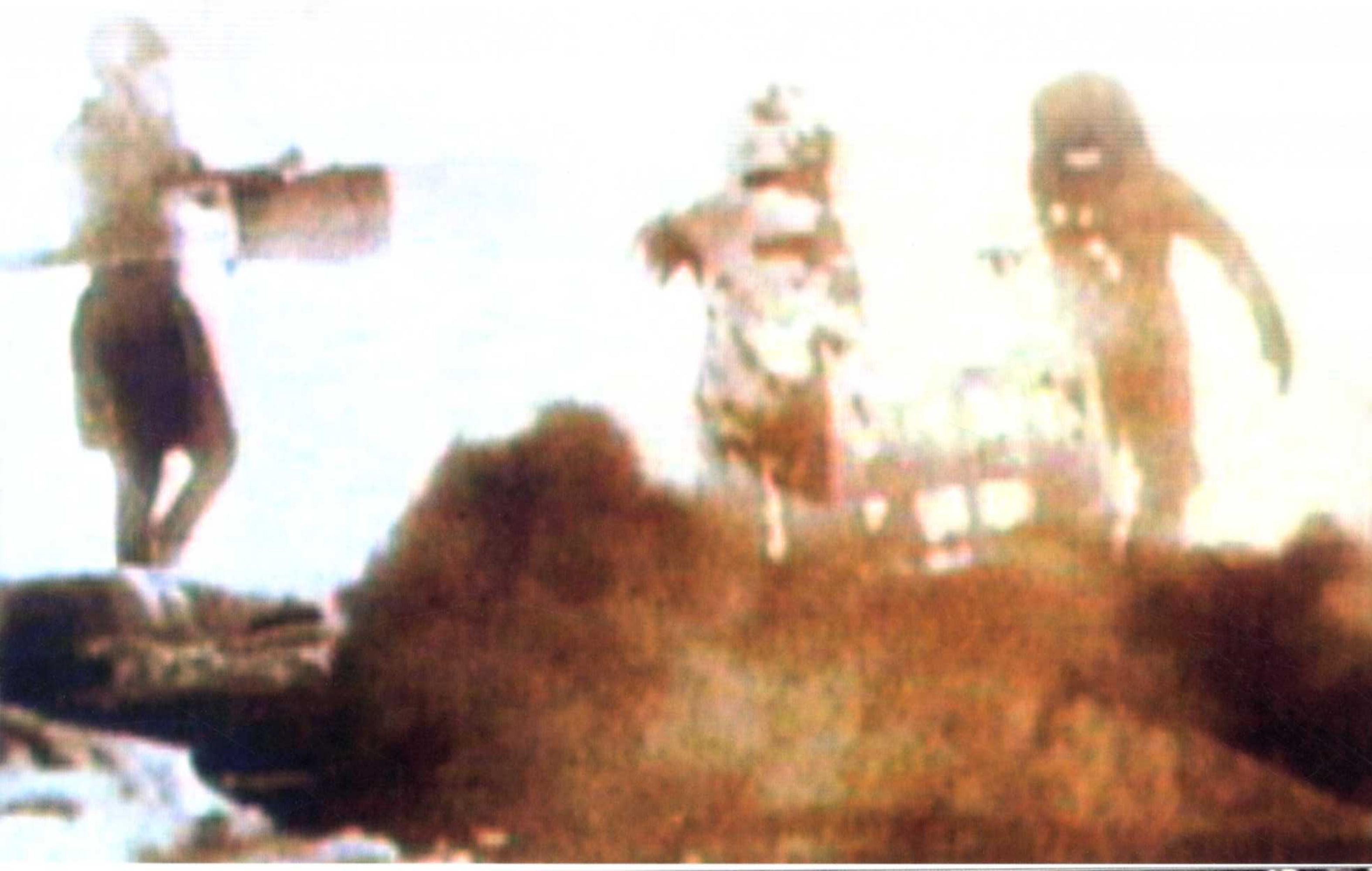
It took many years for the truth about what became known as the Nedelin catastrophe to emerge – the Soviet state was habitually secretive, especially when it came to such sensitive matters. US spy satellites revealed that something had happened at the cosmodrome, but there was no way of knowing quite what – most analysts believed that, coming shortly after the failed launches of Mars 1 and Mars 2 and towards the end of the 1960 launch window for Mars, the explosion had been a disastrous third attempt to launch a Mars probe.

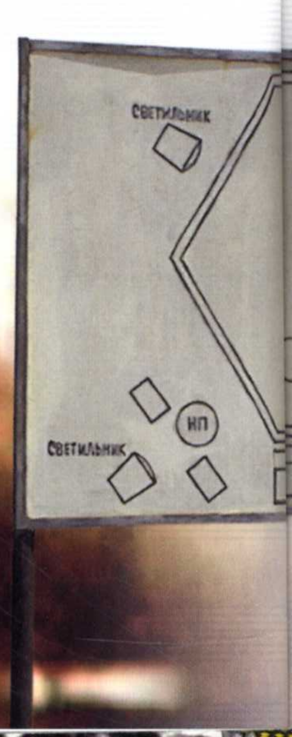
The reality was that the rocket at the heart of the inferno was a prototype Soviet ballistic missile, devised by Sergei Korolev's former deputy and now rival Mikhail Yangel. The disaster had been caused by the impatience of one man and a callous disregard for safety procedures. Once again, the Soviet Union had planned a spectacular, but this time things had gone very badly wrong.

"Above the pad erupted a **column of fire**. In a daze we watched the flames burst forth **again and again until all was silent** ... the bodies were in unique poses – all were without clothes or hair. It was **impossible to recognize anybody**."

Unnamed worker at a nearby observation point

THE FIREBALL STRIKES
The explosion laid waste an area 120m (400ft) in diameter. Many died instantly, but others were trapped by the fence around the pad. The fire raged for two hours before it could be brought under control.





"... cameras ... recorded the scene ... The men on the scaffolding dashed about in the **fire and smoke**; many jumped off and **vanished into the flames.**"

Soviet nuclear physicist and dissident Andrei Sakharov, *Memoirs*, 1990

The rocket on the pad was the R-16 ICBM. While Korolev's R-7 had proved itself a formidable launch vehicle, it had been dismissed as a weapon of war, because it could not be stored with its fuel onboard. Yangel's R-16 was supposed to get around that, and it had been given top priority. Marshall Mitrofan Nedelin, head of Soviet Strategic Rocket Forces, took personal charge and was eager to launch the rocket before the anniversary of the Bolshevik Revolution, on 7 November. On 21 October, therefore, despite the protestations of many engineers who thought it was not ready for launch, the R-16 was moved to the launch pad at Baikonur's Site 41. By 24 October, all was not going well. Nedelin had already refused a request the previous day that the fuel should be drained and the rocket removed from the pad. When a further delay was announced, he insisted on going to the pad in person to see what was happening. With countless checks and procedures to run through in so short a space of time, something was more than likely to go wrong – and it did. At 18:45, the routine resetting of a timer in the command bunker caused the rocket's second stage to ignite, firing directly into the fuel-laden first stage below and creating a devastating fireball.

Mikhail Yangel survived only because he was having a cigarette break with some colleagues at the time of the explosion. The incident robbed him of his ambitions to play a key part in the space programme, but the R-16 did make it into space, just over three months later in February 1961.

"**... people ran** to the side of the other pad, towards the bunker ... but on this route was a strip of new-laid tar, which **immediately melted.** Many got stuck in the hot sticky mass and became victims of the fire."

Andrei Sakharov, 1990

"... a fire took place which caused the destruction of the tanks with components of the propellant. The **casualties numbered up to 100 or more people**, including fatalities – several dozen. Chief Marshal Nedelin was present ... now, the search for him is going on."

Mikhail Yangel notifies the Kremlin

LAUNCH PAD LAYOUT
A present-day map shows how Site 41 looked at the time of the disaster. The R-16 stood at the centre of the hexagon, and the circle shows where Marshal Nedelin was sitting at the time of the explosion.

MEMORIAL TO THE DEAD
This memorial was only erected many years after the disaster but is traditionally visited by officials before every launch.

1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

18 March 1958
Maxime Faget presents a paper on his ballistic launch profile for manned spaceflight to a conference at NACA's Ames laboratories

29 July 1958
Congress approves the creation of a National Aeronautics and Space Administration.

1 October 1958
NASA officially comes into existence.

7 October 1958
T. Keith Glennan publicly announces NASA's manned spaceflight programme, and the formation of the Space Task Group.

17 December 1958
The manned spaceflight programme is named Project Mercury, from a suggestion by Abe Silverstein.

12 January 1959
McDonnell Corporation is awarded the contract to manufacture the Mercury capsules.

9 April 1959
The seven astronauts selected to take part in Project Mercury are presented to the world.

Mercury takes wing

In late 1958, the newly formed NASA announced its manned space programme to the world. But while Soviet engineers could rely on massive rockets to go straight to orbit, NASA would have to proceed more slowly.

Of course, some US engineers had been weighing the options for manned spaceflight since before the launch of Sputnik. Much of the early design work was done at NACA's Pilotless Aircraft Research Division, where forward-thinkers such as Maxime Faget and Robert Gilruth worked out a mission profile that involved lobbing a conical, wingless spacecraft into orbit, its underside fitted with a protective casing, called ablative shielding, that would burn away as it re-entered the atmosphere. Once it reached terminal velocity in the lower atmosphere, parachutes would bring it to a gentle landing.

When NASA opened for business in October 1958, one of Administrator T. Keith Glennan's first decisions was to establish the Space Task Group, a panel of talented scientists and engineers inherited from the various bodies absorbed by NASA, whose role would be to make manned spaceflight a reality. Faget was among those selected in the group, and Gilruth was appointed as its chairman.

A pivotal meeting came on 15 December 1958, when Glennan met with ABMA engineers, including Wernher von Braun, at Redstone Arsenal. Although the Huntsville unit would not be formally absorbed into NASA until 1960 (when it became the Marshall Space Flight Center), they were determined to play a pivotal role in the US manned space programme, offering not just help in the design of launch vehicles to put men in Earth orbit, but a complete step-by-step plan to put Americans on the Moon by 1967.

Steps to orbit

On 17 December, Glennan announced Project Mercury to the world. The plan was to develop the programme incrementally, as different launch vehicles came on stream. A relatively small rocket called Little Joe would carry dummy capsules to high altitude. Redstones and Jupiters would perform ballistic "hops" into space, and finally the US Air Force's giant Atlas ICBM, still in development, would take the capsule into orbit.

But as the programme got started, one question remained – who would be the astronauts? Debate raged within NASA about selection criteria, and it was Eisenhower who ultimately decreed that the astronauts should be test pilots, although some had more radical ideas (see panel, below left). On 9 April 1959, the United States was presented with seven new heroes – the Mercury astronauts who were intended to be the first humans to travel into space.

IN A SPIN
The Multiple Axis Test Inertia Facility (MASTIF) was a Mercury simulator mounted on gimbals that allowed trainees to practise controlling its motion in three different axes.

THE LUCKY SEVEN
The test pilots selected to be Mercury's astronauts inspect a model of the Mercury-Redstone vehicle that would carry manned US missions into space.

TECHNOLOGY

THE MERCURY WOMEN

Early in Project Mercury, it looked as though the USA might pick a woman as its first astronaut. The idea was proposed by Dr. Randolph Lovelace in early 1959, while he was assessing medical criteria for spaceflight. Lovelace argued that women were smaller and lighter than men, required less oxygen and coped better with stress. A group of talented female pilots including Jerrie Cobb (left) travelled to the Lovelace Clinic in secret and underwent rigorous testing in which they proved themselves just as good as male candidates. A couple went on to undertake further training. However, the social attitudes of the time ultimately ensured that none of them would ever make it to space.

The Mercury Seven

The group of astronauts NASA selected to take America into space would become national heroes – but they would also be subjected to a tough training regime to prepare them for orbit.

SUITED UP
The silver spacesuits designed for NASA by the B.F. Goodrich Company, and modelled here by John Glenn, became an iconic image of the Mercury programme.

President Eisenhower made the decision over Christmas 1958 that only military test pilots should be considered for the first phase of the astronaut programme. Despite his military background, he was keen on maintaining a civilian aspect to the space programme (hence the formation of NASA), but in this case he saw that test pilots would have many of the characteristics needed.

So in early January 1959, NASA's selection committee began sifting through the records of 508 potential candidates. Some 110 of these were called for interviews and written tests, and by February the number had been reduced to just 32. All these candidates were then subjected to a battery of medical tests, and 14 were dismissed due to various concerns, leaving 18 that were considered potential astronauts. Politics came into play with the final choice – seven launches were planned for the first phase of the programme, and when Gilruth sat down with the selection committee on 1 April 1959, they were careful to choose three astronauts each from the Navy and the Air Force. The seventh was to come from the Marines.

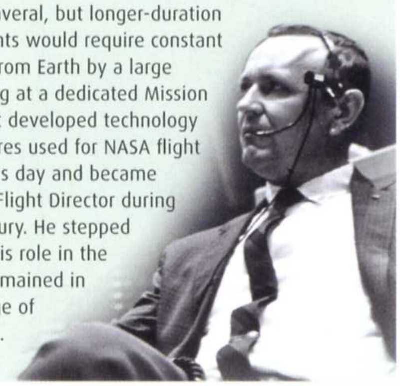
Seven face the press

NASA Administrator T. Keith Glennan introduced his astronauts to the assembled media a week later. They were Scott Carpenter, L. Gordon Cooper, John Glenn, Virgil "Gus" Grissom, Walter Schirra, Alan Shepard, and Donald K. "Deke" Slayton.

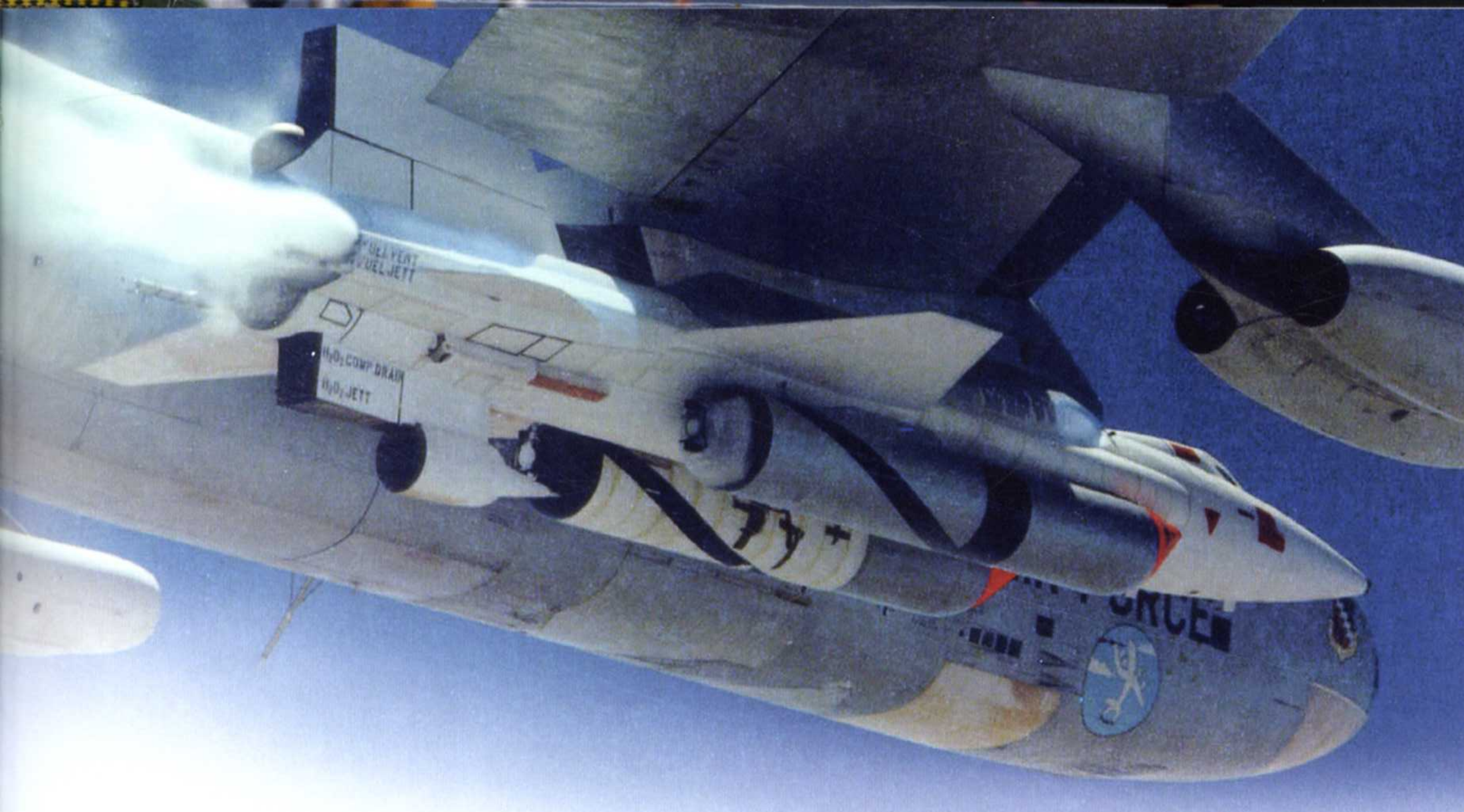
From the start, NASA was careful to court the press and public with carefully arranged photo opportunities and announcements designed to keep interest high. The seven were photographed in their futuristic silver spacesuits, on survival exercises in the desert, and inspecting prototypes under construction at the McDonnell factory. While most of the candidates were taciturn military men, Glenn stood out in the media as the most charismatic and self-deprecating of the group. However, competition among the seven was intense – when asked at that

BIOGRAPHY

CHRIS KRAFT



Virginia-born Chris Kraft (b.1924) was an aeronautical engineer at NACA before its absorption into NASA. In 1958 he was put in charge of developing flight-control systems for Project Mercury. Early satellite launches could be controlled from the blockhouses at Cape Canaveral, but longer-duration manned flights would require constant monitoring from Earth by a large team working at a dedicated Mission Control. Kraft developed technology and procedures used for NASA flight control to this day and became NASA's first Flight Director during Project Mercury. He stepped back from this role in the 1960s but remained in overall charge of flight control.



ROCKET PLANE
While the Mercury Seven were still in training, the hypersonic X-15 rocket plane was setting a series of aviation records. Several of its pilots would earn USAF astronaut wings, and there was a friendly rivalry between test pilots and astronauts.

first press conference who believed they should be the first into space, each raised his hand, except for Glenn and Schirra, who raised both.

The right stuff

In between press calls, the astronauts underwent intensive training. As well as the survival exercises in water and on land (just in case they made landfall over inhospitable territory), there were lessons in astronomy, space science, and engineering, alongside parachute jumps, parabolic flights to train for weightlessness, and endless simulations. And on top of all this, they had to maintain their flying skills. One thing above all disappointed the astronauts – in the initial plans, the Mercury capsule was so completely automated that it left them with little to do. Despite all their training, it seemed they would be little more than passengers, reduced to hoping that the engineers on the ground had got it right. Teasing from test-pilot colleagues, and NASA's plans to use chimps in place of astronauts on some test flights, reinforced the feeling, and Deke Slayton was only half joking when he talked about engineers who believed they would have a far simpler job if they "didn't have to worry about the bloody astronaut".

FLYING THE "VOMIT COMET"
A pair of Mercury astronauts enjoy a few seconds of weightlessness in the cabin of a converted C-131 aircraft. The so-called Vomit Comet flew to high altitudes, then dropped on a parabolic flightpath so that its occupants went into freefall.

Despite the media push for manned spaceflight, there were still many who felt there was no point in sending a man to do a machine's job, including scientists such as James Van Allen and some military strategists. Fortunately for the astronauts, there were also influential believers, such as von Braun and some politicians, who saw the value of spaceflight in shaping their new vision of America.

And so many of Mercury's systems were redesigned to give the pilot more to do. While the entire system was designed to operate automatically or under control from the ground, the astronauts would be able to take control of thrusters to adjust spacecraft altitude and to manually trigger the retro-rocket burn for re-entry.

HIGH FLIERS, TOP GUNS
The Mercury Seven assemble for a portrait in front of a Convair F-106 B, one of several high-performance aircraft purchased by NASA for use by the astronauts in maintaining their finely honed flying skills.

1 April 1959
The Space Task Group's selection panel chooses seven potential astronauts for the Mercury programme.

9 April 1959
The Mercury Seven are introduced to the world at a press conference.

27 April 1959
The Mercury astronauts report for duty.

July 1959
Training begins using the MASTIF gimbal rig.

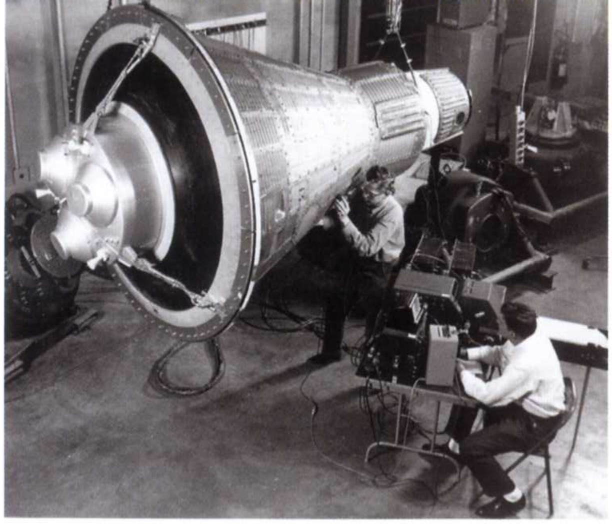
December 1959
The astronauts begin weightless flight training.

February 1960
The Mercury Seven study celestial navigation at Morehead Planetarium, North Carolina.

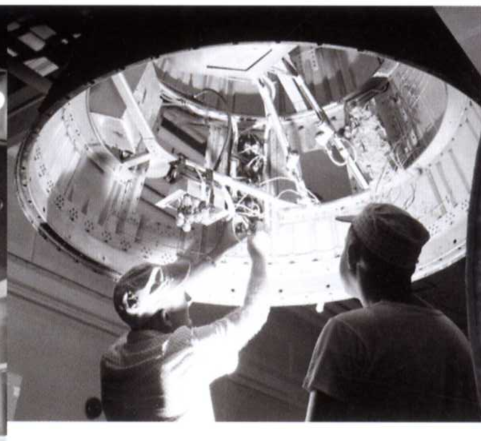
February 1960
The seven begin "water egress training".

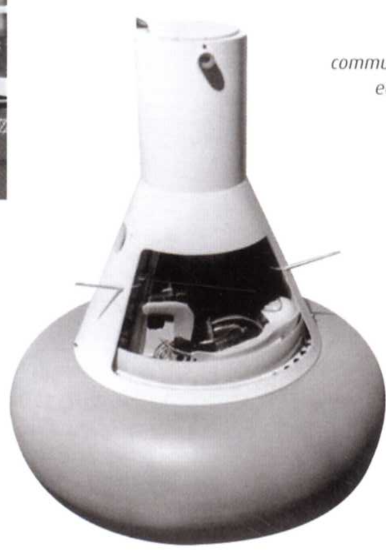
1 April 1960
The astronauts complete centrifuge training.

July 1960
The seven undergo survival training in the Nevada Desert.

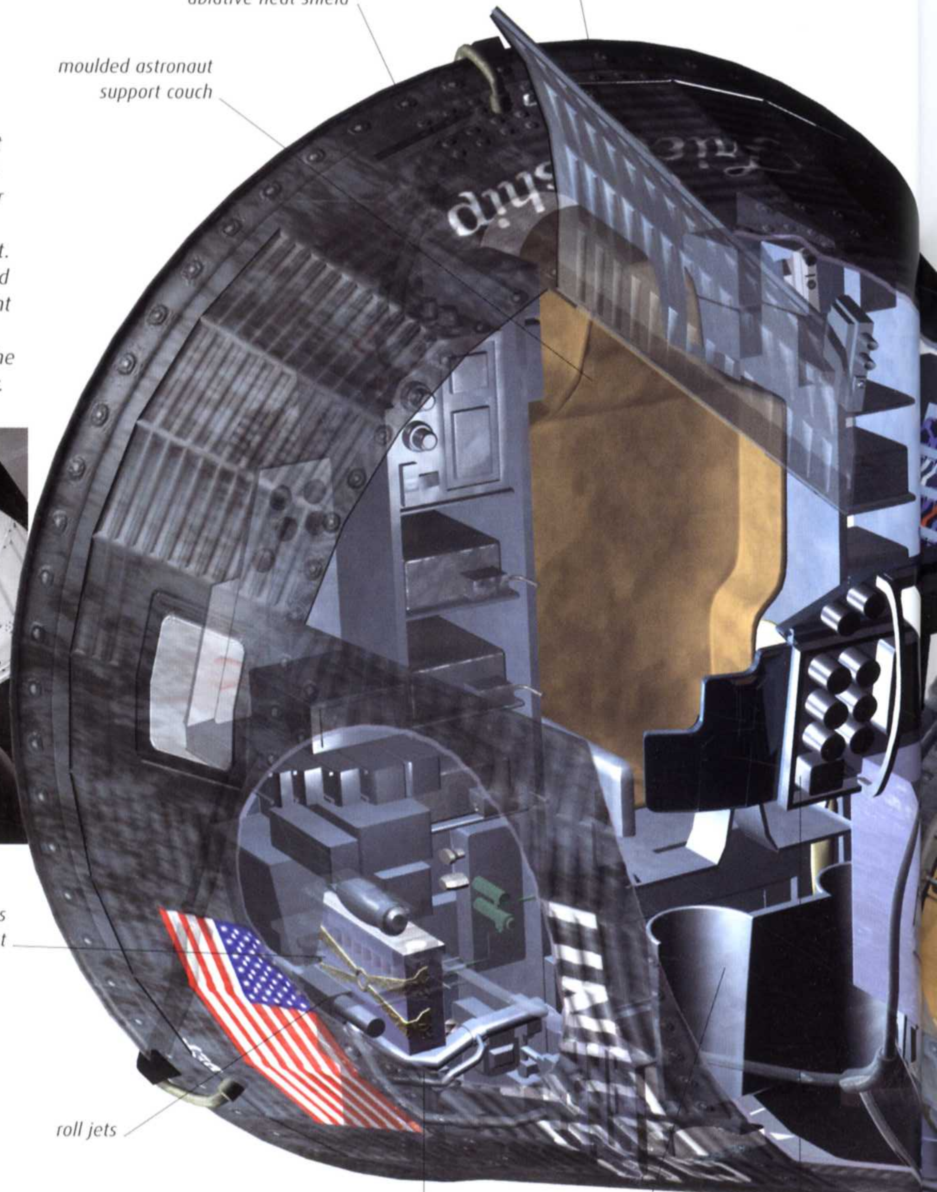


BOILERPLATE CAPSULE
The first dummy capsules were built in-house at NASA's Langley division for test launches with the Little Joe rocket. They were designed to mimic the weight and aerodynamic characteristics of the completed Mercury.





CAPSULE TESTING
Model capsules were tested in wind tunnels with scaled-down parachutes (above). The inflatable ring that would cushion the splashdown and keep the spacecraft afloat was also tested (right). Meanwhile, engineers set to work on increasingly complex boilerplate capsules (above right).



TECHNOLOGY

NASA'S FIRST MANNED SPACECRAFT

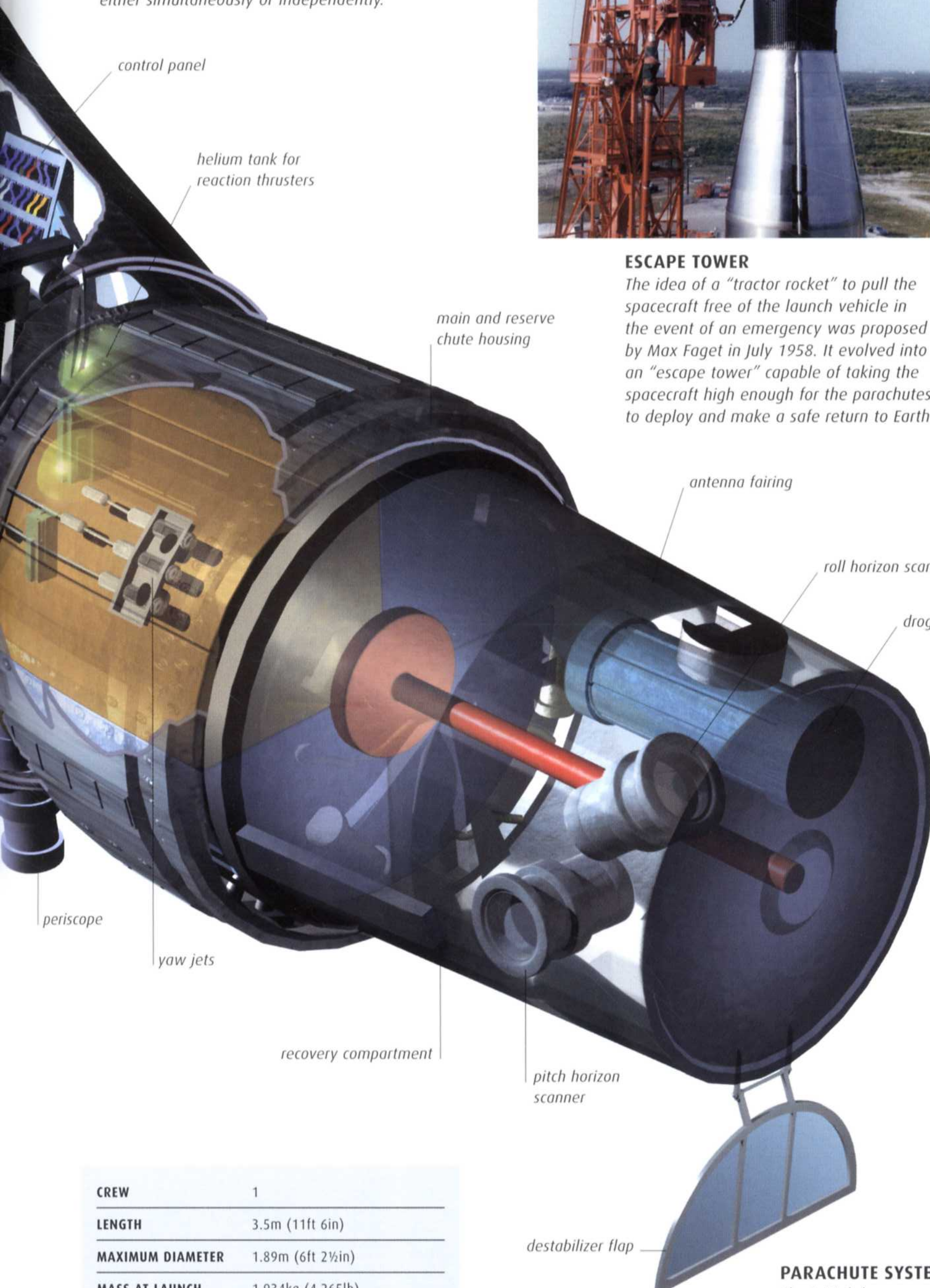
Mercury capsule

NASA's first manned spacecraft was just one-third the weight of the Soviet Vostok – it had to be in order to be launched by the weaker US rockets of the time. Yet both vehicles had to address the same problems of life support in orbit, re-orientation in space, and re-entry into the atmosphere. A variety of designs were pitched by potential contractors, but NASA's Space Task Group already knew they wanted a conical, wingless capsule that would re-enter the atmosphere on a ballistic trajectory. In January 1959, McDonnell Aircraft Corporation were awarded the prime contract.

FLIGHT CONTROLS
Compared to the minimalism of Vostok, the Mercury capsule was lined with banks of switches and controls. This was largely thanks to the persistent lobbying of the Mercury Seven astronauts, who argued that there was little point in sending highly trained pilots into space as mere passengers (or "spam in a can", as a sceptical Chuck Yeager memorably put it).

THE MERCURY SPACECRAFT

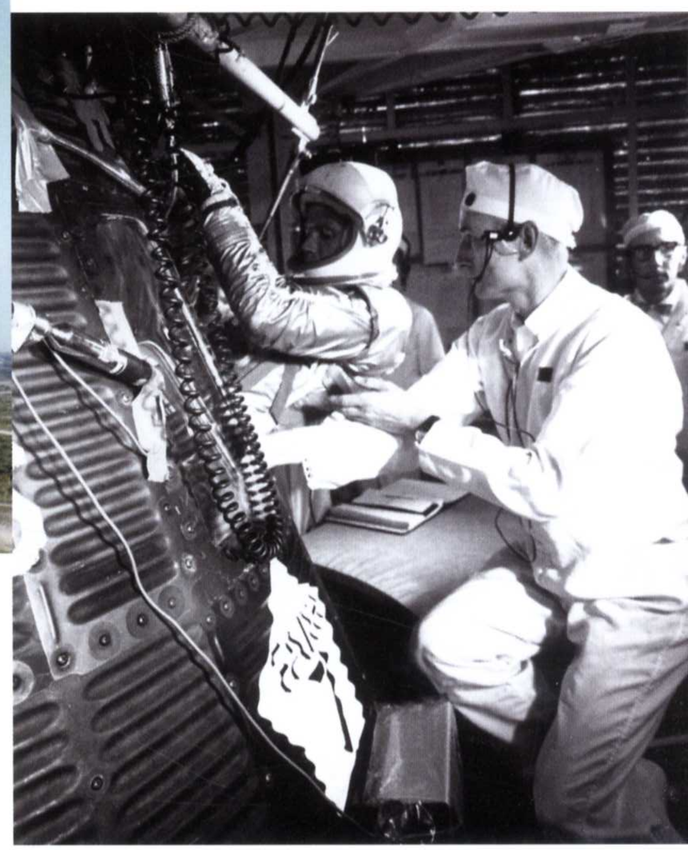
The astronaut sat inside the cramped Mercury capsule on a made-to-measure pilot's seat, his back to the heat shield and retropack. Though attitude control was supposed to be guided by the Automatic Attitude Control System, the Mercury pilots frequently used a hand controller that could adjust the spacecraft's yaw, pitch, and roll either simultaneously or independently.



CREW	1
LENGTH	3.5m (11ft 6in)
MAXIMUM DIAMETER	1.89m (6ft 2½in)
MASS AT LAUNCH	1,934kg (4,265lb)
MASS AT LANDING	1,130kg (2,493lb)
ENGINES	solid rocket retro-pack
MANUFACTURER	McDonnell Aircraft Corporation

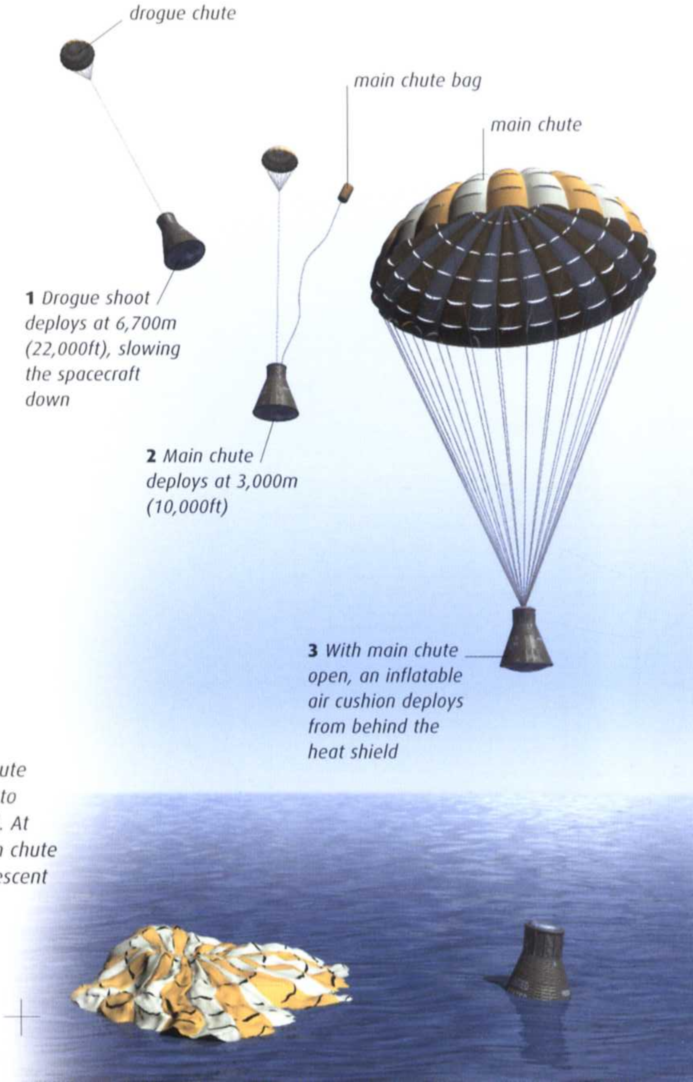
ESCAPE TOWER

The idea of a "tractor rocket" to pull the spacecraft free of the launch vehicle in the event of an emergency was proposed by Max Faget in July 1958. It evolved into an "escape tower" capable of taking the spacecraft high enough for the parachutes to deploy and make a safe return to Earth.



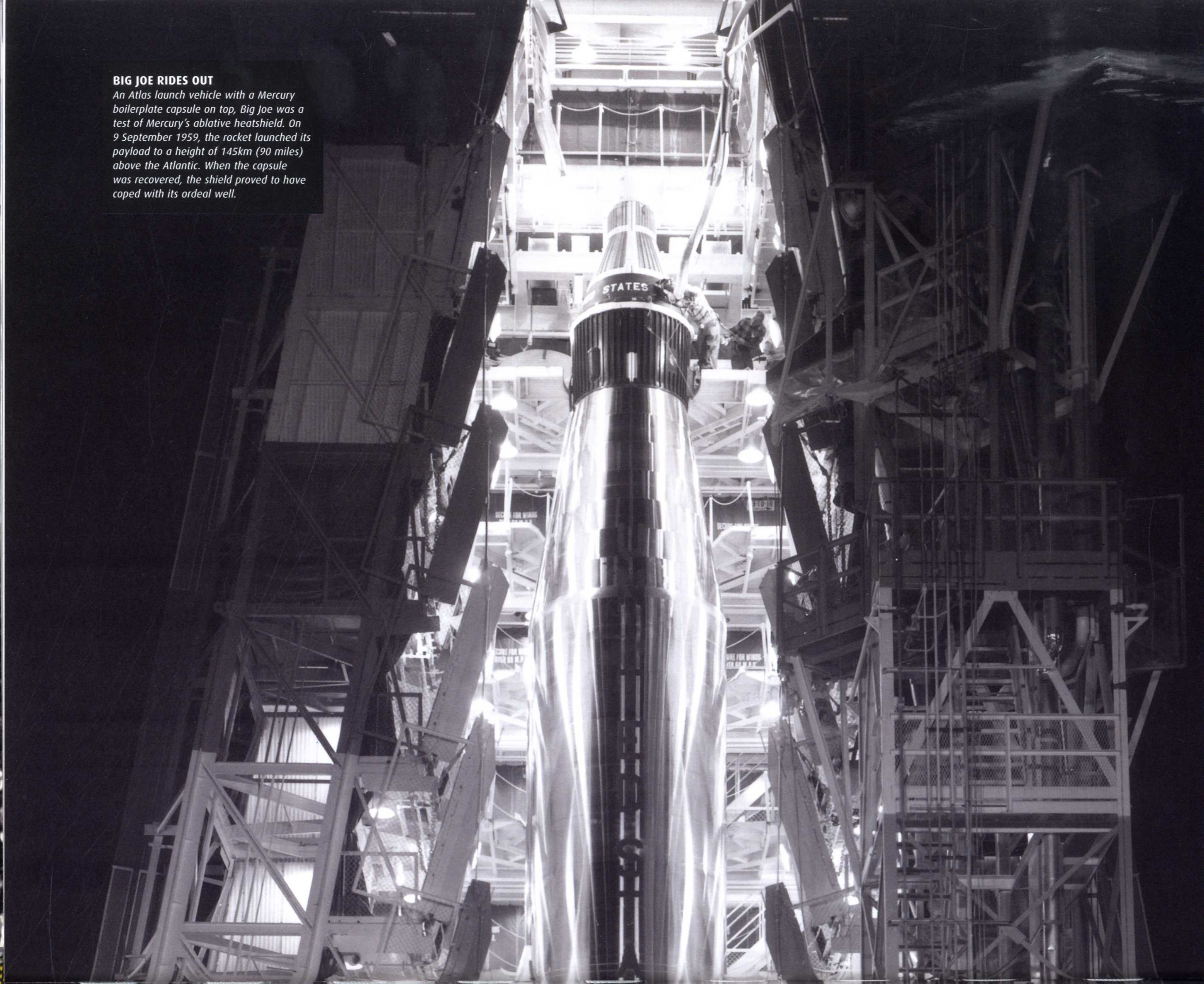
NAME AND NUMBER

Gordon Cooper is helped aboard his Faith 7 *capsule for a flight rehearsal. Each Mercury capsule was given a name by its pilot, followed by the number 7. Chrysler employee Cecelia Bibby painted the logos onto the side of the spacecraft.*



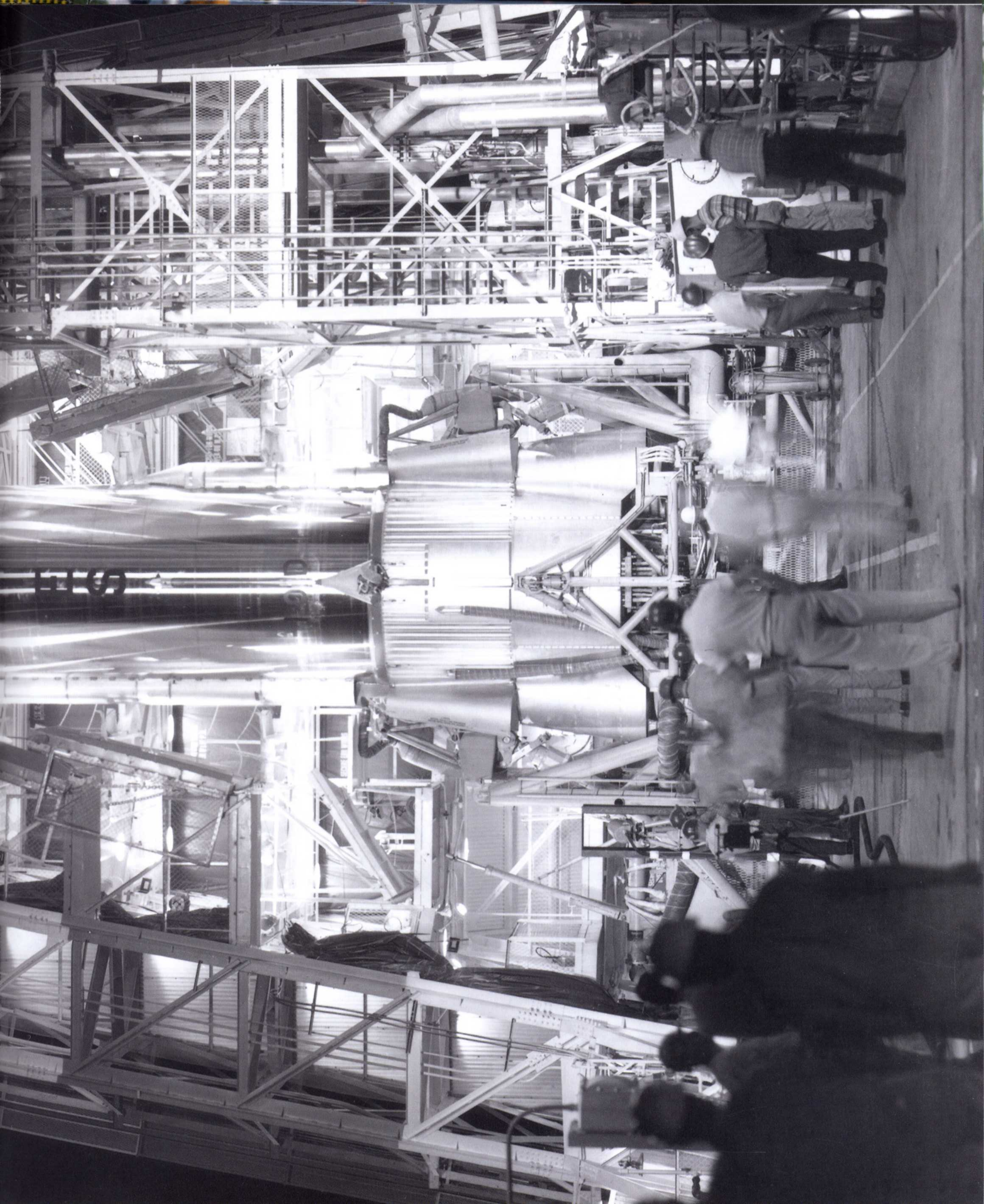
PARACHUTE SYSTEM

The initial drogue parachute slowed the craft's speed to 111m (365ft) per second. At 3km (10,000ft), the main chute was released, slowing descent to 9m (30ft) per second.



BIG JOE RIDES OUT

An Atlas launch vehicle with a Mercury boilerplate capsule on top, Big Joe was a test of Mercury's ablative heatshield. On 9 September 1959, the rocket launched its payload to a height of 145km (90 miles) above the Atlantic. When the capsule was recovered, the shield proved to have coped with its ordeal well.



9 May 1960
First in a series of trials, known as "beach aborts", at Wallops Island test the Mercury capsule's escape systems.

29 July 1960
The launch of a boilerplate Mercury capsule aboard an Atlas rocket ends in a crash after 59 seconds.

8 November 1960
The first of the Little Joe launches takes off from Wallops Island to test the spacecraft's structural integrity. However, a rocket fault destroys the spacecraft 15 seconds after launch.

19 December 1960
The Mercury-Redstone 1A mission launches an unmanned capsule on a suborbital flight.

31 January 1961
Mercury-Redstone 2 takes off, carrying Ham the chimp on a sub-orbital flight.

24 March 1961
The successful test flight of Mercury-Redstone mission MR-BD qualifies the rocket for manned flight.

Tests and space chimps

Before NASA would commit to send an astronaut into space, they tested the Mercury technology thoroughly with a series of unmanned launches and a number of flights with primate passengers.

While the Mercury Seven spent their days in training or parading before the press, the engineers at McDonnell and the Space Task Group's offices at Langley Field, Virginia (the former NACA laboratories), were labouring to complete the vehicle that would eventually take them into space.

FIT FOR AN APE
Ham and the later space chimp Enos (shown here) both wore custom-made spacesuits for their flights. In Ham's case, the suit probably saved his life when a loose valve resulted in a sudden drop in cabin pressure.

Little Joe launches

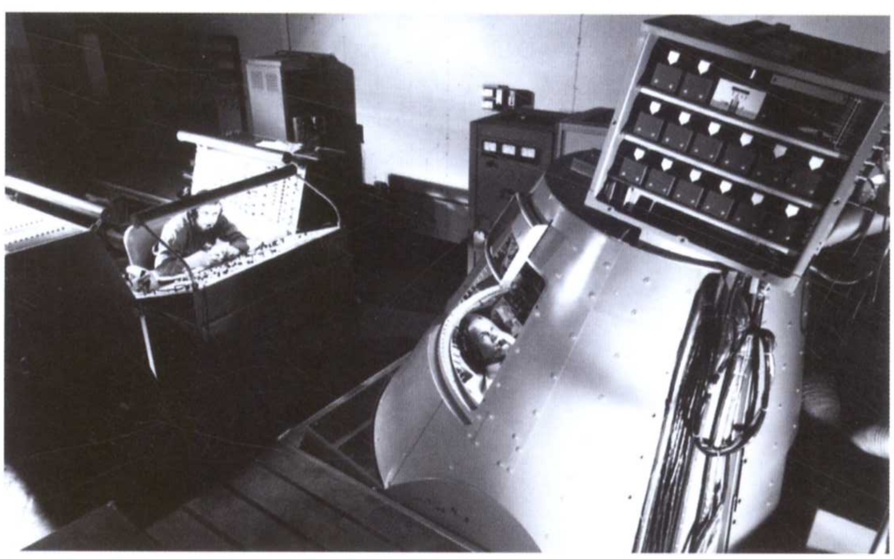
To test the basic principle of the conical Mercury capsule, a number of bare-bones boilerplate models were produced. These could be launched on top of the relatively cheap Little Joe booster rocket – a two-stage launch vehicle in which each stage was itself a cluster of four solid-fuelled rockets.

The boilerplate capsules and their rockets were fitted with instruments to record the stresses and temperatures encountered in each flight. Low-altitude flights tested the escape system, while higher trajectories allowed the engineers to see how Mercury behaved as it re-entered the atmosphere and to test the performance of prototype heat shields. Two of the later Little Joe missions carried passengers – rhesus monkeys called Sam and Miss Sam – in order to test their ability to survive the forces experienced in a real Mercury mission. Both animals survived with no obvious ill effects.

While Soviet engineers typically sent dogs on their early test flights, NASA's medical experts felt that primates would provide the best data about the stresses of space travel – if a monkey could survive a Mercury launch and re-entry in good condition, then it seemed likely that a human could do. And there was another advantage of using primates – some were smart enough to be trained, allowing doctors to assess how they fared mentally in orbit.

The first ape in space

A group of six chimps were trained for test flights aboard the Mercury capsule, and a male called Ham (see panel, right) was selected for a sub-orbital flight aboard a Redstone-launched Mercury on 31 January 1961. Other tests with the Redstone had gone well, but the Atlas vehicle needed to put the



SIMULATOR TRAINING
While Ham took to the skies, the Mercury Seven were still stuck on the ground – here John Glenn is undergoing a simulated mission on the Mercury Procedures Trainer at Langley Field, Virginia.

capsule into orbit was still hitting problems, and it was clear that NASA's first human spaceshot would have to be on a sub-orbital trajectory. Ham's flight was a dress rehearsal for the human flight. It hit a number of snags, but the stresses the chimp overcame convinced the experts that a Mercury mission was survivable even if things did go wrong. However, von Braun insisted on another unmanned launch of the Redstone, infuriating Alan Shepard, who was slated to pilot the first sub-orbital flight (several of the seven already felt slighted by the fact that an ape was taking the lead in the space programme instead of them). A final test of the Mercury-Redstone configuration on 24 March went perfectly, but as it turned out problems with Shepard's *Freedom 7* capsule would delay the launch still further. In the meantime, the Soviets were about to seize the initiative, and the headlines, once again.

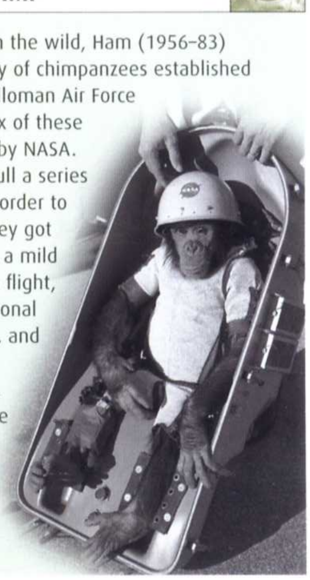
CHIMP ASCENDING
During the launch of Mercury-Redstone 2, the main engine burned through its fuel supply faster than expected, and Ham had to endure far higher g-forces than intended, peaking at 15 g. He survived unscathed, but the fault also meant that Ham was weightless for more than six-and-a-half minutes – two minutes longer than planned.

HAM COMES HOME
The commander of recovery ship USS Donner *greets Ham as he arrives onboard. The capsule overshot its planned splashdown and landed out of sight of the recovery fleet. By the time helicopters reached it, the spacecraft had begun to sink.*

HAM GRITS HIS TEETH
Cameras monitored Ham's reactions throughout the flight – during ascent and re-entry, he experienced extreme acceleration, but he quickly recovered and performed his tasks well.

BIOGRAPHY

HAM THE SPACE CHIMP



Captured as an infant in the wild, Ham (1956–83) became part of a colony of chimpanzees established in the late 1950s at Holloman Air Force base in New Mexico. Six of these chimps were recruited by NASA. They were trained to pull a series of levers in the correct order to receive a reward – if they got it wrong, they suffered a mild electric shock. After his flight, Ham retired to the National Zoo at Washington, D.C. and then to North Carolina, where he died in 1983. Most of the colony were not so lucky, but the last were retired in 1997 and settled at a sanctuary in Florida.

The first man in space

The launch of the first cosmonaut into space on 12 April 1961 shook the world almost as much as the launch of Sputnik 1 three-and-a-half years earlier. Yet Yuri Gagarin's short flight in Vostok 1 almost ended in disaster.

VOSTOK LIFTS OFF
The R-7 launch vehicle carrying Vostok 1 blasts free of the launch pad at Tyuratam in Kazakhstan. Onboard, Gagarin (left) had little freedom to move and still less to influence his spacecraft.

By the end of March 1961, the first Soviet manned spaceflight had been authorized, but who would be on board? The choice was down to two men – the evenly matched friends Gagarin and Titov.

When the State Commission met on 7 April, they agreed that Titov was probably the fitter of the two trainees. However, Gagarin had done a better job of treading the fine line between unquestioning obedience and independent thought, and it was this that won him the coveted prize. The fact that he had a peasant background similar to Khrushchev's own (see panel, right) may also have given him an edge over the middle-class Titov. The choice was made in closed session, but the commission sat again the next day, with Gagarin, Titov, and the cameras present, to repeat its choice in public.

At 5:00am, Moscow time, on 11 April, the R-7 launcher with Vostok 1 attached rolled out along the track leading from the assembly complex to the launch pad at Tyuratam. A day of rehearsal and exhaustive testing followed, and that night the medical team monitored the sleep patterns of Gagarin and his reserve through sensors inside their mattresses (a counterproductive measure, since the two men convinced the doctors they were having a restful night by lying rigid in their beds and barely sleeping at all).

BIOGRAPHY
YURI GAGARIN

Gagarin was the son of peasant farmers, born on a collective farm near Smolensk. After showing early academic promise, he studied engineering at college, before enrolling as a fighter pilot in 1957. Selected for cosmonaut training in 1960, he soon became Korolev's favourite among the "Top Six" trainees (the two are pictured together here), which eased his selection as the first cosmonaut. After his historic flight, however, Gagarin had trouble adjusting to his new-found celebrity. Paraded as a Hero of the Soviet Union, he fell into depression, and died in a jet crash while training for a return to space on Soyuz 3.

Into orbit

On the morning of 12 April, Korolev personally woke his cosmonauts at 5:30am. After a final series of medical checks, both astronauts were suited up, and Titov had to suffer the agony of riding with Gagarin in the bus to the launch site, then waiting on stand-by as his comrade was secured inside the Vostok capsule. Only then was Titov taken to an observation bunker to remove his spacesuit.

Meanwhile, engineers worked to secure Gagarin, plugging him into a variety of monitors and life-support systems. The controls of Vostok 1 were locked on autopilot and could be freed only by entering a three-digit code, intended to be sent from ground control in an emergency. However, no fewer than four people revealed the code to Gagarin before he was sealed into the spacecraft. After a last-minute glitch with a circuit monitoring the hatch closure, countdown began in earnest. At 9:06am the R-7's main engines fired and slowly began to lift Gagarin towards orbit, on a 108-minute flight that would make history (see over).

Vostok's orbit initially carried it northeast across Siberia. Here, an accurate flightpath was calculated by controllers from telemetry signals received at a series of remote listening posts. Then the spacecraft swept southeast across the Pacific Ocean and onto the night side of the Earth.

Even as Gagarin passed out of radio contact into the western hemisphere, Radio Moscow was already announcing the latest Soviet success. The announcement was rather premature, for the most dangerous part of the flight was yet to come.

As Vostok 1 began re-entry above Africa, explosive charges blew the main links between the Instrument and Descent Modules – but a thick bundle of wires did not detach as planned, and Vostok 1 began to spin wildly as it plunged back into the atmosphere. Fortunately, hot gas building up around the spacecraft eventually burned through the cable, and Gagarin's capsule came free. Seven kilometres (4½ miles) above the ground, automatic pressure sensors blew the hatch and launched Gagarin into the air in his ejector seat. He parachuted to the ground as planned in Saratov province, southern Russia.

9 March 1961
A Vostok test capsule is successfully launched.

25 March 1961
A second Vostok test capsule is successfully launched. The same day, Gagarin and Titov practise boarding the Vostok 1 capsule on the launch pad.

27 March 1961
Following the successful test flights, a manned launch is approved.

3 April 1961
Gagarin and Titov rehearse donning their spacesuits and are filmed boarding the Vostok capsule.

7 April 1961
The cosmonauts rehearse emergency procedures in case of a launch failure. Meanwhile, a closed session of the State Commission selects Gagarin to be the pilot for Vostok 1, with Titov as backup.

8 April 1961
A filmed meeting of the State Commission repeats its decision for the cameras, with Gagarin and Titov present.

11 April 1961
Gagarin and Titov undergo final pre-launch medical tests. Gagarin is given the all-clear for his historic flight.

12 April 1961
Yuri Gagarin, aboard Vostok 1, becomes the first man to travel in space.

1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

EXPERIENCE

MAN ENTERS SPACE

FAMILY MAN
Gagarin met Valentina Goryacheva while in training at Orenburg Pilot's School. They married in 1957 and had two daughters, Elena and Galya.

108 minutes

Yuri Gagarin's ascent into history began at 9:06am on 12 April 1961, Moscow time, as the R-7 rocket carrying Vostok 1 fired its engines and slowly lumbered off the pad at Baikonur. Before leaving Moscow, the first cosmonaut had recorded a message that might, in other circumstances, have been his epitaph:

"**Dear friends, known and unknown to me**, my dear compatriots and all people of the world! Within minutes from now, a mighty Soviet rocket will boost my ship into **the vastness of outer space** … My whole life is now before me as a single breathtaking moment."

Two minutes into the flight, Gagarin felt a jolt of acceleration as the R-7's booster rockets separated and the core continued alone. After five minutes, that too was exhausted. By the time it too had separated, the payload shroud surrounding Vostok 1 had already fallen away. As the final rocket stage pushed him towards orbit, Gagarin reported back:

"I can see the Earth. **The visibility is good** … I almost see everything. There's a certain amount of space under cumulus cloud cover. **I'm continuing the flight – everything is good**."

Four minutes later, the engines cut out and the upper stage fell away, leaving Gagarin in an elliptical orbit with a period of just over 89 minutes. As Gagarin lost radio contact with Baikonur, he briefly made contact with the Kolpashevo tracking station, then was alone for three minutes as his spacecraft swept above northern Siberia. Last contact with his homeland came as he flew into the Pacific night, maintaining contact with a station at Khabarovsk on the east coast.

Even as Gagarin finally lost contact, Radio Moscow and the Soviet news agency TASS were reporting the successful launch:

"The Soviet Union has successfully launched a manned spaceship-satellite into an orbit around the Earth. Present aboard the spaceship is the **pilot cosmonaut, Yuri Alekseyevitch Gagarin**, an Air Force pilot, 27 years of age. The spaceship was launched about 9am, Moscow time, April 12, 1961. **The spaceship is named Vostok** and weighs 4,725 kilograms, including the pilot but excluding the last stage of the carrier rocket. The hermetically sealed cabin of the spaceship is equipped with a two-way radio, TV, and a telephone-type communication system."

FROM BUS TO CAPSULE
Gagarin and his backup Gherman Titov rode together in the bus to the launch pad. By 7:10, Gagarin was seated in the cramped Vostok cabin, and an hour later, he was sealed in to await the launch itself.

FINAL WAVE
Yuri Gagarin is photographed for the last time before being sealed inside Vostok 1 by chief constructor Oleg Ivanovsky. The fully automated spacecraft had a keypad to release the manual controls, with a code that would be sent from the ground in an emergency. But Nikolai Kamanin, Sergei Korolev and Ivanovsky had all informed Gagarin of the code before launch.

HAPPY LANDINGS
As the recovery team moved in to retrieve the charred Vostok 1 Descent Module, Gagarin was already being greeted as a hero by well-wishers who had heard reports on the radio. Later he had time for some brief reflection before being thrust into the limelight once again.

“To be **the first to enter the cosmos**, to engage, single-handed, in an unprecedented duel with nature – **could one dream of anything more?”**

Yuri Gagarin, recorded in Moscow before the launch

Gagarin flew back into daylight over the Atlantic at 10:10, and Vostok 1 automatically aligned itself for its re-entry burn. As he flew on towards Africa, the lone cosmonaut continued transmitting his regular status messages, though there was no one within range to receive them. Fifteen minutes into the new day, and still 8,000km (5,000 miles) from landing, Vostok fired its engines for a 42-second braking manoeuvre. As the Instrument and Descent modules separated, the main electrical cable linking them stuck in place, and Gagarin found himself shaken and spun around as the linked modules plunged into the atmosphere.

Finally, after ten minutes, heat from re-entry burned through the cable and the Instrument Module fell away at around 10:35. The Descent Module now righted itself, but there were still 20 minutes of ballistic descent to endure, during which Gagarin almost blacked out under forces of up to 8*g*. Passing over the Black Sea, Vostok 1 re-entered Soviet airspace, slowing all the while. Finally reaching the required altitude of 7km (4½ miles) at 10:55, the spacecraft automatically ejected the escape hatch. Seconds later, Gagarin was blasted free on his ejector seat as the craft deployed its descent parachute.

“When they saw me in my spacesuit and the parachute dragging alongside as I walked, they started to **back away in fear.** I told them, don’t be afraid. I am a Soviet like you, who has **descended from space,** and I must find a telephone to call Moscow!”

Gagarin describes his meeting with a farmer and her daughter

JUBILANT KHRUSHCHEV
The Soviet premier received the news of Gagarin’s safe return with delight, and shortly afterwards Radio Moscow reported: “At 10:55 Cosmonaut Gagarin safely returned to the soil of our motherland.” Two days after the flight, Gagarin flew to Moscow to meet the Soviet leadership and was greeted as a national hero by the largest crowds the city had seen since the end of the Second World War.

1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

Vostok sets the pace

The later Vostok missions achieved a series of space firsts designed to keep the Americans on the back foot in the Space Race. Vostok 2, for example, saw cosmonaut Gherman Titov spend an entire day in space.

6 August 1961
Gherman Titov, aboard Vostok 2, becomes the first person to spend a day in orbit.

11 August 1962
Andrian Nikolayev is launched into orbit in Vostok 3.

12 August 1962
Pavel Popovich, aboard Vostok 4, enters orbit close to Nikolayev – for the first time there is more than one person in space at the same time.

15 August 1962
Vostoks 3 and 4 re-enter the atmosphere and land within minutes of each other.

14 June 1963
Vostok 5 carries Valery Bykovsky into orbit.

16 June 1963
Vostok 6 joins Bykovsky's capsule in orbit. Valentina Tereshkova becomes the first woman to travel in space.

19 June 1963
Vostoks 5 and 6 successfully return to Earth.

The decision to aim for a day-long flight was partly driven by necessity – Vostok's inclined orbit and the Earth's slow rotation meant that, within a few hours of launch, the capsule would no longer be over Soviet territory. Mission planners had to choose between a three-orbit mission, which would be over in five hours, or an entire day in space. The publicity offered by a day-long flight doubtless swung the decision.

However, there was also a scientific motivation as no one knew what the effects of extended weightlessness might be on the human body. A day-long flight would allow time for the cosmonaut to eat and sleep in orbit, as well as test how he coped psychologically. One problem became clear a few hours after the launch of Vostok 2 on 6 August 1961.

Group flights

As Titov attempted to sleep, he became nauseous. However, he had no problem with eating and drinking, briefly took control of the spacecraft, and used a film camera to record the view from his cockpit window. Re-entering Earth's atmosphere, Vostok 2 experienced similar separation problems to those on Vostok 1, but Titov made a safe return to Earth by parachute after 17 orbits. Although later missions would continue to extend flight times, this was unlikely to provide the stream of propaganda demanded by the Kremlin, and longer missions alone could provide little in the way of new scientific data or engineering results. With the limitations of the Vostok spacecraft itself, there was only one way to proceed – a so-called "group flight".

After a series of delays (largely caused by problems in development of Zenit, a spy satellite that took priority for R-7 launches in late 1961), specialist training for a group of cosmonauts got under way in early 1962. Nevertheless, when Vostok 3 blasted off, piloted by Andrian Nikolayev, on 11 August 1962, the world had little idea of what to expect. Precisely 23 hours 32 minutes later, as Vostok 3's orbital path took it back across Tyuratam, Pavel Popovich's Vostok 4 rose to join it, arriving in orbit just 6.5km (4 miles) away. The cosmonauts were able to establish

THE FIRST WOMAN IN SPACE
Despite rumours that Tereshkova suffered from severe space sickness in orbit, and was uncommunicative with ground controllers, Vostok 6 still fulfilled all of its goals.

VOSTOK 1: GAGARIN THE HERO
After his return to Earth, Gagarin was fêted as a national hero and sent on a world tour that saw him treated like a movie star. Here, he studies newspaper coverage of his flight with his wife, Valentina, and Nikita Khrushchev.

VOSTOK 2: GHERMAN TITOV
Titov, seen here in the bus with his backup Nikolayev (right), was the fittest of the first trainees and the one who had coped best in the isolation tests. This made him the obvious choice for the first longer-duration spaceflight.

VOSTOK 3: ANDRIAN NIKOLAYEV
Nikolayev's tolerance of isolation training earned him the nickname Iron Man and the chance to set a new endurance record. He later married fellow cosmonaut Valentina Tereshkova, though the marriage eventually collapsed.

BIOGRAPHY

GHERMAN TITOV

Just a month short of his 26th birthday when he took to the skies aboard Vostok 2, Gherman Stepanovich Titov (1935–2000) is still the youngest person to have travelled in space. Born in a small village in the Altai region, he trained as a pilot at Stalingrad, before his recruitment to the Soviet cosmonaut programme. His day-long flight in 1961 made him an international celebrity, and the Kremlin propagandists sent him on tours around the world. From 1962, he retrained as a test pilot alongside some of the other cosmonauts, and led the team training to fly the planned Spiral spaceplane. However, the spacesickness he suffered aboard Vostok 2, coupled with a tendency to clash with his superiors, meant that he never flew in space again.

direct radio contact between the spacecraft before they gradually drifted apart. When the they returned to Earth within minutes of each other on 15 August, Nikolayev had been in space for four days.

Although Korolev wanted to continue the Vostok programme, he was overruled – work on the Voskhod modification was to take priority. But the last paired Vostok mission saw another propaganda coup, as Valery Bykovsky's Vostok 5, launched on 14 June 1963, was joined in orbit two days later by Valentina Tereshkova, the first female cosmonaut, in Vostok 6. Tereshkova was an expert parachutist and one of a group of women trained for flight by Kamanin and Korolev. The two cosmonauts returned to Earth on 19 June, marking the end of the Vostok programme.

VOSTOKS 3 AND 4: THE WORLD LISTENS IN
Muscovites crowd around a car radio reporting the formation flight of Vostoks 3 and 4. Although the Vostoks were unable to manoeuvre in orbit, it would be three years before the US could improve on this early space rendezvous.

VOSTOK 4: PAVEL POPOVICH
Popovich's flight was intended to continue after Vostok 3's return to Earth, but confusion broke out when he reported storms (groza) below. This was an agreed codeword to indicate nausea, and so an early landing was ordered.

VOSTOKS 5 AND 6: TERESHKOVA/BYKOVSKY
Nikita Khrushchev parades Valentina Tereshkova and Valery Bykovsky in Moscow's Red Square following the successful mission of Vostoks 5 and 6. Bykovsky's five days in orbit set a record for lone spaceflight that stands to this day.

1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

2 May 1961
A planned launch of the *Freedom 7* capsule is scrubbed due to cloud cover. The identity of the astronaut onboard is revealed to the press.

4 May 1961
The launch of *Freedom 7* is delayed for a second time due to bad weather.

5 May 1961
Freedom 7 finally launches at 09:34, on a 15-minute suborbital flight. Shepard is the first American in space.

25 May 1961
President John F. Kennedy makes his famous speech to Congress, vowing that an American will walk on the Moon before the decade is out.

18 July 1961
Weather delays the planned launch of *Liberty Bell 7*.

21 July 1961
After another delay, Gus Grissom's *Liberty Bell 7* capsule is finally launched successfully into space. However, a hatch malfunction after splashdown floods the capsule and Grissom is lucky not to drown.

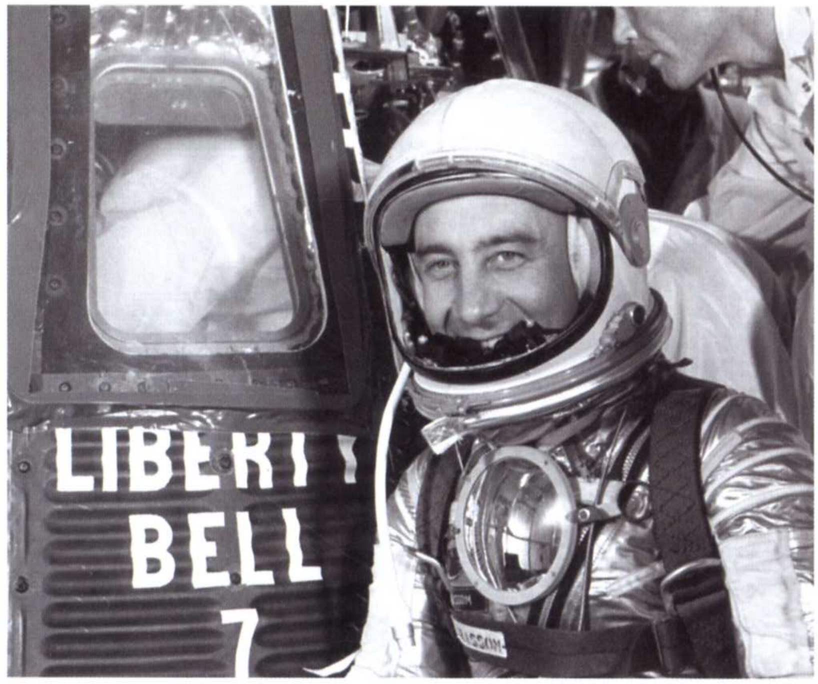
Mercury rising

In the aftermath of Gagarin's Vostok flight, the US was once again looking outpaced in the Space Race. An early and successful start to the Mercury programme was vital – and, fortunately, NASA delivered.

The Soviet announcement of Vostok 1's successful mission had not surprised the rest of the world as much as the sudden appearance of Sputnik 1, but it was still galling for the Americans to be beaten by a matter of weeks. Alan Shepard in particular was furious at what he saw as delays caused by overcautious management. In the White House, meanwhile, recently inaugurated President John F. Kennedy found himself on the receiving end of the same accusations of complacency that he had levelled at the Eisenhower administration.

The first manned Mercury spacecraft was finally ready for launch on 2 May 1961. The name of *Freedom 7*'s astronaut had been a closely guarded secret, and it was only after a cancellation due to poor weather that Alan Shepard's identity was revealed to the media. Further delays followed, until conditions were right for launch on 5 May. Even then, there were repeated delays in the countdown. Eventually Shepard's patience ran out – "Why don't you light the damned candle, 'cause I'm ready to go!", he snapped at mission control.

And so, at 9:34am, Mercury-Redstone 3 lifted off the pad carrying its pilot into history. Compared to Vostok 1's trip, *Freedom 7*'s flight into space was just a short hop, lasting only 15 minutes 22 seconds, but it punched above its weight thanks to NASA's decision to broadcast the entire event. Forty-five million Americans watched live on their televisions, and the images helped convince the world that the US was keeping up with the Soviets. In one way, they were actually ahead – Shepard was the first astronaut to return from space aboard his capsule, though this was not known at the time because of the secrecy surrounding Vostok 1's return.



WAITING TO GO
Grissom looks cheerful moments before climbing aboard Liberty Bell 7. *The window in the enlarged escape hatch can be seen behind him.*

BIOGRAPHY
ALAN SHEPARD

New Hampshire-born Alan Bartlett Shepard (1923–98) saw active service during the Second World War aboard the destroyer *USS Cogswell*. He then trained as a naval pilot, gaining his wings in 1947, before qualifying as a test pilot in 1950. He was selected for the Mercury programme in 1959. After becoming the first American in space, he just missed the chance of a second Mercury flight – NASA had briefly considered a three-day mission before deciding to concentrate on the Gemini programme. He became Chief of NASA's Astronaut Office in 1963 and lost the opportunity to command the first Gemini mission due to a problem with his inner ear. After surgery in 1969, he joined the Apollo programme and in 1971 commanded Apollo 14. He retired from NASA in 1974 and went into business, serving on the board of several corporations.

Liberty Bell cracks

On 8 May, the Mercury astronauts enjoyed a celebratory dinner at the White House, while back at NASA thoughts were already turning to a second suborbital flight. Almost everything on *Freedom 7* had worked perfectly, and if all went well with the next mission, the third flight could be sent into orbit.

Gus Grissom named his capsule *Liberty Bell 7*, and in tribute to the original Liberty Bell (rung in 1776 in Philadelphia before the reading of the Declaration of Independence), a crack was painted down one side.

This was to prove prophetic – *Liberty Bell*'s flight on 21 July went perfectly, but shortly after splashdown the explosive bolts holding a new and larger escape hatch in place triggered accidentally, flooding the capsule and sending it sinking to the bottom of the Atlantic. Grissom himself, his spacesuit filling with water, was lucky to escape with his life.

GRISSOM STEPS OUT
Gus Grissom strides purposefully towards the Mercury-Redstone 4 rocket, with technicians and support personnel gathered at its base, on the morning of 21 July 1961.

EXPERIENCE
ALAN SHEPARD'S SUBORBITAL HOP

Almost in orbit

Unlike the flight of Vostok 1 – which was prepared for and carried out in almost total secrecy until it was actually under way – the launch of Mercury-Redstone 3 from Cape Canaveral carrying Alan Shepard's *Freedom 7* capsule happened amid a blaze of publicity on 5 May 1961.

ONE OF A KIND
Alan Shepard's crooked grin appears during rehearsals for fitting his pressure suit. Shepard was a man of contradictions with a changeable personality – perhaps fittingly described as mercurial.

Shepard was woken in the early hours of the morning. After breakfasting with his backup, John Glenn, and other members of the team, he was given a final medical examination and pronounced fit to fly. Before he suited up, biosensors were placed on his skin in a variety of places. By 3:55am EST, he was boarding the transit bus for the journey out to the launch pad. As he later recalled:

> "The excitement really didn't start to build until the trailer – which was carrying me, with **a spacesuit with ventilation and all that sort of stuff** – pulled up to the launch pad."

Shepard entered the spacecraft at 5:20am – inside he found a note that had been left by Glenn, which read "No handball playing here!". The launch was set for 7:25 – barring delays, he had 125 minutes to wait. But at T-15 the first in a series of holds was called. After an hour's wait, and with another hour at least to go, Shepard had a problem, which he communicated to Gordon Cooper in launch control. As the communications transcript records, the capsule's electrical supply had to be turned off while Shepard relieved himself:

Alan Shepard: Gordo!
Gordon Cooper: Go, Alan.
AS: Man, I got to pee.
GC: You what?
AS: You heard me. I've got to pee. I've been up here forever … tell them to turn the power off!
GC: Okay, Alan. Power is off. Go to it.

MAN IN A CAN
Shepard later commented: "It's a very sobering feeling to realize that one's safety factor was determined by the lowest bidder on a government contract."

FOUR STEPS TO SPACE
Shepard and Glenn suited up together with the assistance of suit technician Joe Schmitt, but only Shepard got to make the fateful walk to the gantry elevator, carrying his portable air unit. Once there, he was helped into the tiny capsule by the ground crew. Schmitt then shook his hand while the ground crew wished the astronaut "Happy landings!"

> "I think **all of us certainly believed the statistics** which said … probably 88% chance of mission success and maybe **96% chance of survival**. And we were willing to take those odds."

Alan Shepard, February 1991

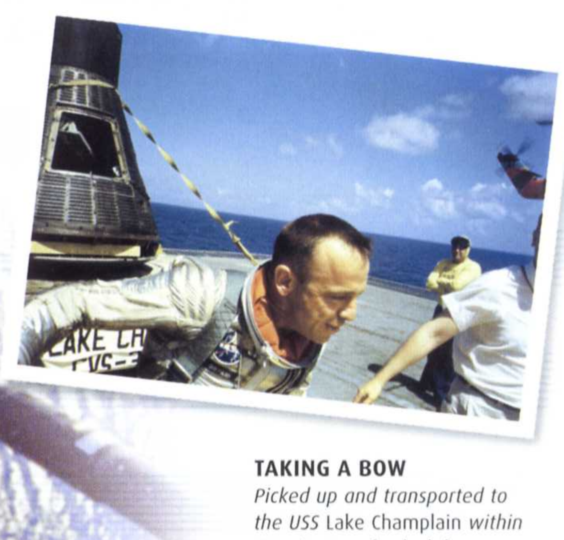
Four hours and 14 minutes after Shepard boarded *Freedom 7*, launch control "lit the candle" and Shepard soared skywards. For 45 seconds the ascent was smooth, but then vibrations began to build up as the rocket approached the sound barrier. Two minutes into the flight, Shepard was experiencing maximum acceleration of around 6*g*. Another 20 seconds, and the Redstone engine beneath him shut down. Still soaring skywards, *Freedom 7* jettisoned its launcher and escape tower as its external temperatures rose to 104°C (220°F). Shepard described what he could see:

"On the periscope ... **What a beautiful view.** Cloud cover over Florida – three to four tenths near the eastern coast. Obscured up to Hatteras ... I can see [Lake] Okeechobee. Identify Andros Island. Identify the reefs."

The capsule had automatically turned itself around by the time it reached its peak altitude of 187km (116 miles). Shepard now assumed manual control to fine-tune the capsule's attitude and fire the retrorockets. As he plummeted back down the re-entry curve, he jettisoned the retropack strapped across the capsule's heat shield. Plunging back into the atmosphere, Shepard felt the strain of up to 11.6*g* before the drogue parachute was deployed at 6,400m (21,000ft). At 3,000m (10,000ft) the main parachute slowed the capsule further, dropping it back to a splashdown at a relatively sedate 10.5m (35ft) per second.

"The rocket had **worked perfectly**, and all I had to do was survive the re-entry forces. **You do it all**, in a flight like that, in a rather short period of time, **just 16 minutes** as a matter of fact."

Alan Shepard, February 1991



TAKING A BOW

Picked up and transported to the USS Lake Champlain *within 11 minutes of splashdown, Shepard had a moment to acknowledge the applause of the crew before answering a call from President Kennedy.*

29 November 1961
John Glenn is selected as pilot for the first orbital Mercury flight, with Scott Carpenter as his backup.

23 January 1962
The first in a series of postponements hits the scheduled launch of *Friendship 7*. A series of hitches, caused by bad weather but also by a fuel leak, eventually delays the launch for almost a month.

20 February 1962
An Atlas rocket finally launches Glenn and *Friendship 7* into orbit. The flight lasts a little less than five hours and mostly goes smoothly, although re-entry is a more traumatic experience than Glenn had expected.

1 March 1962
Four million people line the streets of New York for a tickertape parade to honour Glenn.

Mercury in orbit

John Glenn's three historic orbits around the Earth in February 1962 briefly put NASA back on a more even footing with its Soviet rivals. However, the first orbital Mercury was not entirely flawless.

Despite the near-disastrous ending of Grissom's *Liberty Bell 7* mission in July 1961, the Mercury capsules had proved themselves reliable in flight. Meanwhile, the Atlas ICBM also seemed to have overcome its early glitches – now it was time to combine the two and put Mercury into orbit.

However, any hopes that NASA might have had of levelling the score with its Soviet rivals were dashed on 6 August by Gherman Titov's successful day-long flight aboard Vostok 2 (see p.80). Despite pressure from some quarters to rush to a manned launch, Gilruth's Space Task Group, now in the process of relocation from Langley to the new Manned Spaceflight Center at Houston, Texas, continued to insist on a steady process of qualification. The first unmanned launch of a Mercury capsule on an Atlas rocket took place on 13 September and went flawlessly, but before NASA would trust a man to orbit, it insisted on a full dress rehearsal with another space chimp.

As a result, Enos, a male chimp like Ham, was launched into space on 29 November aboard Mercury–Atlas 5. The flight went well, despite a few problems with control of the spacecraft's attitude in orbit, and Enos coped magnificently with 181 minutes of weightlessness and higher G-forces than even Ham had tolerated. The Mercury–Atlas combination was now ready to take its first human passenger.

BIOGRAPHY

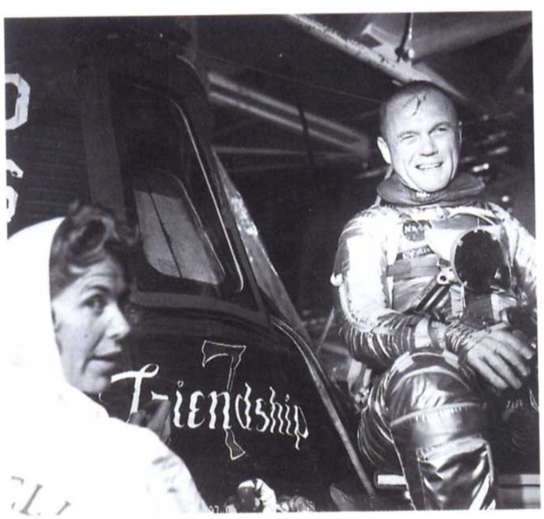
JOHN GLENN

Ohio-born John H. Glenn (b.1921) was militarily the senior member of the Mercury seven, a highly decorated captain in the Marine Corps with experience in the Second World War and the Korean War. His charismatic personality made him a particular media favourite among the seven, and after his return to Earth he retired from NASA to follow a career in business and politics, eventually as Democratic Senator for Ohio (1975–1999). In 1998 he finally returned to orbit at the age of 77, becoming the oldest person to travel in space during a nine-day mission aboard the Space Shuttle *Discovery* (see p.207).

A saga of delays

NASA was understandably eager to launch Glenn into orbit before the end of 1961, but a series of snags conspired against them. Problems with the hardware during testing at Cape Canaveral pushed the launch back, and a provisional date of 16 January was finally set. Problems with the Atlas fuel tanks held that up until 23 January, and poor weather then caused a further week of delays. While fuelling

GLENN IN ORBIT
The first American in orbit enjoys the view from high above the Earth (note the reflection in his visor). Throughout the flight, an automatic camera recorded his every action.



FRIENDSHIP 7
Each astronaut got to choose the name of his own craft. Here, Glenn poses with Chrysler employee Cecelia Bibby, the painter responsible for each of the emblems.

GLENN GIVES THE SALUTE
An ebullient Glenn finally boarded his spacecraft at 6:03am. He had already been awake for four hours, and had to wait almost four more before launch.

CLIMBING ABOARD
Once Glenn had clambered into position, 70 bolts secured the hatch in place. Halfway through the process, a broken bolt was found, so the whole process had to be restarted.

SUNSET FROM SPACE
As Glenn flew over the Indian Ocean, he described the "beautiful" sunset. It lasted longer than he had expected, and even over the night side of the Earth an arc of blue daylight lingered on the horizon.

the rocket in preparation for a 1 February launch, engineers discovered a serious fuel leak, and repairs took a further fortnight, by which point the weather had closed in again. It was not until 19 February that it began to clear, and preparations could be made for a launch the next day.

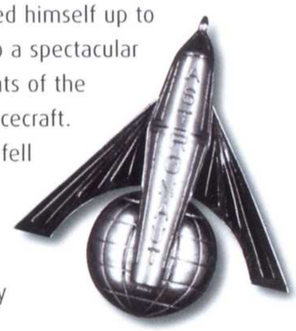
The flight of *Friendship 7*

At 09:47am local time on 20 February, Glenn's spacecraft finally soared into the clear blue skies above Cape Canaveral. The launch went perfectly, and *Friendship 7* was soon in an orbit between 159 and 265km (99 and 165 miles) above the Earth.

The capsule's flight path took it east across the Atlantic, over tracking stations in the Canary Isles and Nigeria, then out above the Indian Ocean and across the night side of Earth. As it left Australia behind and flew into sunrise over the Pacific, Glenn reported seeing tiny glowing specks dancing outside the capsule. The mystery of these "fireflies" would eventually be solved by Scott Carpenter (see over).

Glenn had successfully used the capsule's thrusters to turn his spacecraft around over the Atlantic so he was facing forwards, but a problem began to develop with the automatic control of the yaw thrusters as he approached the west coast of the USA, and he now had to maintain the capsule's attitude manually. During the second 89-minute orbit, a number of further problems developed. The need for manual control had drained the capsule's fuel supply quite rapidly, and Glenn was told to let it drift to preserve fuel for later. More seriously, during the first pass over Cape Canaveral, a capsule sensor indicated that the heat shield and landing cushion were no longer securely in place. In fact, it seemed that they were held on only by the retro-rocket pack strapped across the shield. After some analysis, Flight Director Chris Kraft decided that the pack should be kept in place, rather than jettisoned as planned, during re-entry.

As *Friendship 7* flew back across the Pacific on its final orbit, Glenn adjusted its attitude before firing the retro-rockets to drop out of orbit over California. Re-entry with the rocket pack still in place required more manual control than usual, but Glenn proved himself up to the task and was treated to a spectacular light show as fiery fragments of the pack trailed behind the spacecraft. Splashdown in the Atlantic fell 60km (40 miles) short of predictions, but Glenn's capsule was soon being hoisted aboard the recovery ship *USS Noa*, safe after 295 minutes in orbit. Later tests showed that the sensor, not the shield itself, had been faulty.



MARINE AWARD
Glenn was awarded a special medal by the US Marine Corps to mark his successful orbital flight.

TECHNOLOGY

THE MERCURY–ATLAS LAUNCHER

The Atlas D launcher used in the later stages of the Mercury programme was a modified version of the US Air Force's Atlas ICBM. More sophisticated variants are still in use today – coupled with a variety of upper stages, they form the backbone of the US space programme. A unique feature of the Atlas is its single-skinned design – the outer hull itself acts as the fuel tank, reducing the rocket's weight and increasing its range. The Atlas D had a distinctive configuration sometimes referred to as "1.5 stage" – three engines at the base of the rocket all drew fuel and oxidant from the same tanks and fired in parallel during launch. The two flanking engines then shut down and fell away.

MISSILE ROW

This 1964 aerial shot of Cape Canaveral shows the view north along the coast and up Missile Row, a range of launch pads used for testing the Redstones and early ICBMs, from which many of the Mercury missions blasted off. NASA's larger Apollo-era pads are under construction in the distance.

SPECTACULAR AURORA
Mercury–Atlas 7 blasts into the early morning sky in May 1962. Scott Carpenter's spacecraft, Aurora 7, *got its name from the street where Carpenter lived as a child.*

LOCATION MAP
Cape Canaveral lies along the Florida coast, at the southern end of the US eastern seaboard. This location ensures relatively reliable weather, and the islands to the east are ideal for tracking launches.

Later Mercury missions

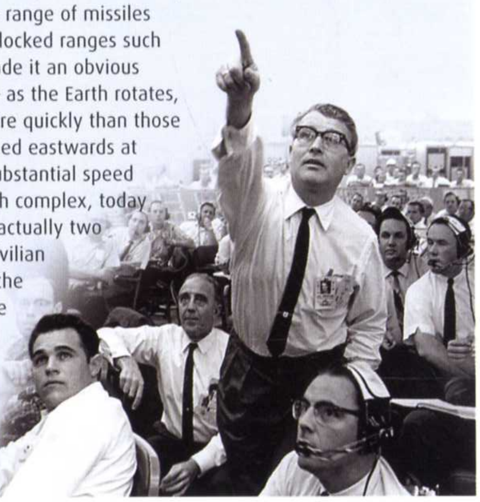
Having finally reached orbit almost a year behind the Soviet Union, NASA used the remaining Mercury missions to extend American experience in space and investigate the possibilities of science in orbit.

When John Glenn was allocated the first Mercury orbital flight in late 1961, Deke Slayton was told he would be the second American into orbit. But by the time Glenn had made his historic flight, fate had intervened – doctors discovered that Slayton had a slightly erratic heartbeat. The unlucky astronaut was grounded, and so it was Scott Carpenter whose *Aurora 7* capsule entered orbit on 24 May 1962. This three-orbit flight was essentially a repeat of Glenn's, but this time the astronaut could concentrate on science rather than the condition of his spacecraft. Carpenter made a brief study of how fluids behaved in the weightless conditions of orbit, ate a meal, and photographed the Earth from above. He also accidentally solved the mystery of Glenn's orbital "fireflies" – approaching his third dawn, Carpenter accidentally knocked his head against the cabin wall, and dislodged a shower of sparkling ice crystals from the exterior. Snags with guidance and alignment systems caused problems during re-entry, and Carpenter splashed down more than 400km (250 miles) off target. By the time the recovery crews reached him, he had escaped through the top of the capsule and was floating on a life raft.

TECHNOLOGY

CAPE CANAVERAL

NASA's major launch site grew up at Cape Canaveral in Florida for a variety of reasons. The site, to the north of an established US Air Force base, was first earmarked for ballistic missile tests in 1949, as the range of missiles being tested began to outgrow landlocked ranges such as White Sands. Its location later made it an obvious place to attempt satellite launches – as the Earth rotates, areas close to the equator move more quickly than those near the poles, and a vehicle launched eastwards at relatively low latitudes receives a substantial speed boost to help it into orbit. The launch complex, today known as Kennedy Space Center, is actually two separate establishments – NASA's civilian and commercial launch pads are in the northern half, on Merrit Island, while the Air Force operates a military launch facility to the south. In reality, though, civilian launches often take place from the military pads, and vice versa.



BIOGRAPHY

WALTER SCHIRRA

The pilot of *Sigma 7*, Walter Schirra (b.1923) is the only astronaut to take part in the Mercury, Gemini, and Apollo programmes. Born in New Jersey into a family of fliers (his father had flown acrobatic displays while his mother was a "wing walker" on some of his flights), Schirra started flying in his early teens. A graduate of the US Naval Academy, he saw action in the final months of the Second World War and the Korean War, before becoming a test pilot. After *Sigma 7*, he flew as Command Pilot aboard Gemini 6, steering his spacecraft to its historic rendezvous with Gemini 7. His final spaceflight was as Commander on Apollo 7, the first manned test of the US lunar spacecraft.

Sigma and *Faith*

Carpenter's re-entry problems turned the emphasis of Walter Schirra's *Sigma 7* mission back to engineering. During six orbits of the Earth on 3 October, much of the time was spent testing the automatic control systems. Schirra also tested elastic devices for exercise in space, attempted to steer his capsule by the stars, and made the first live TV broadcast from space. Re-entry this time was perfect, and *Sigma 7* splashed down in the Pacific Ocean.

The last Mercury mission, piloted by Gordon Cooper, was also by far the longest – 22 orbits over a period of 34 hours. The capsule, *Faith 7*, needed modification to support an astronaut for this long, and so launch did not take place until 15 May 1963. During his flight, Cooper was occupied with a range of experiments, including the release and tracking of a strobing microsatellite from the capsule. He also studied the Earth from orbit – his reports of seeing individual roads and houses on the ground below made some on the ground think he was suffering from hallucinations, but they ultimately paved the way for the modern science of remote sensing.

Following Cooper's successful Pacific splashdown, some at NASA pushed for a three-day Mercury mission. But it was time to move on. In May 1961, the President had given NASA a new and exciting goal – they were going to the Moon.

15 March 1962
Scott Carpenter is moved up the Mercury flight roster to replace Deke Slayton on the second orbital Mercury mission, after the discovery that Slayton has a minor heart defect.

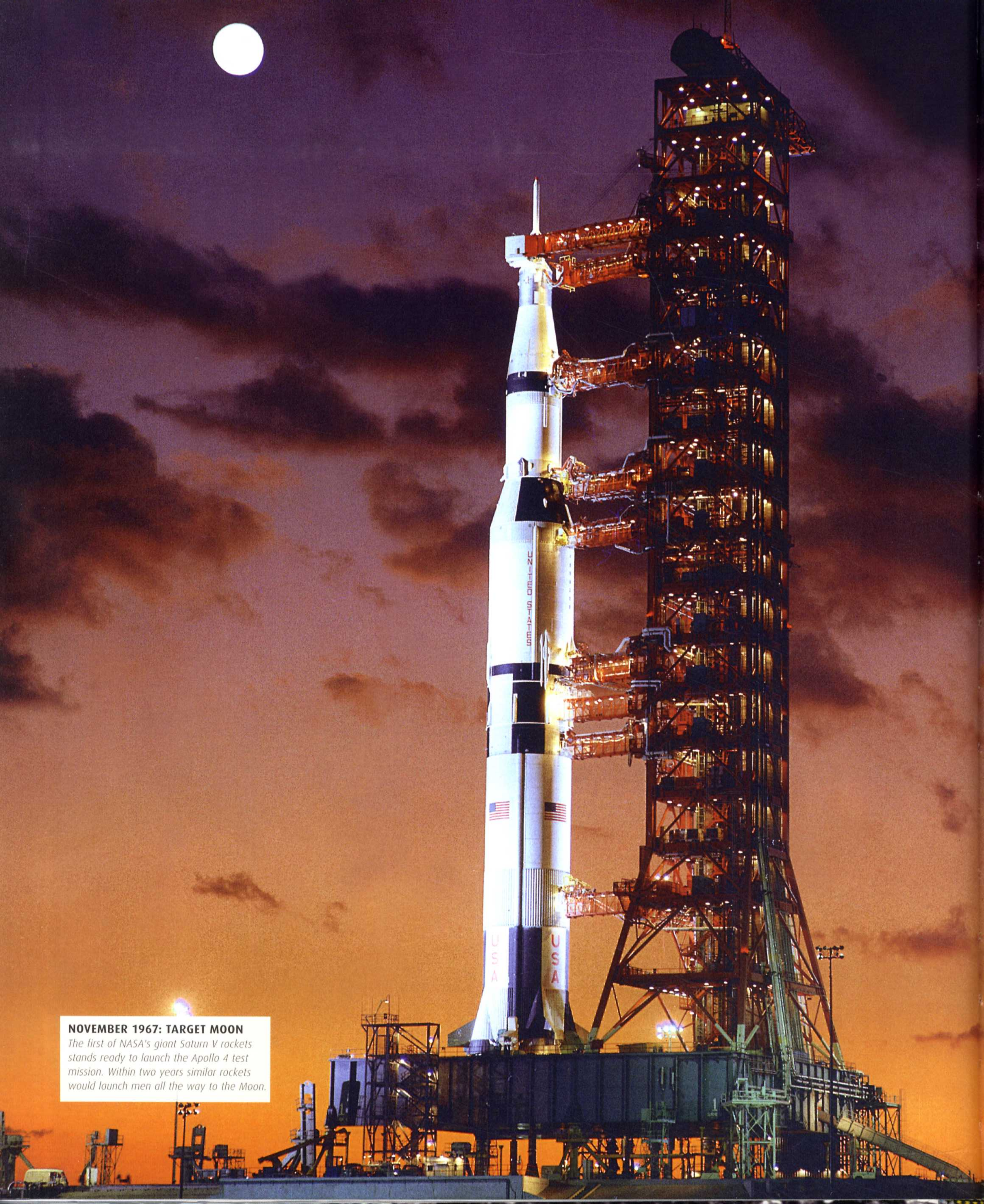
24 May 1962
Carpenter and *Aurora 7* launch on time at 07:45. During the mission, the spacecraft uses more manoeuvring fuel than expected, and as a result splashes down 400km (250 miles) off target. Carpenter has to board his life raft and wait several hours for rescue.

3 October 1962
Walter Schirra's six-orbit flight aboard *Sigma 7* is completed without a hitch.

14 May 1963
The scheduled launch of Gordon Cooper's *Faith 7* is postponed due to a problem at a radar tracking station.

15 May 1963
Faith 7 launches successfully. Cooper completes 22 orbits of the Earth and successfully deploys a tethered balloon for studying conditions around the Earth.

21 May 1963
The end of the Mercury programme is marked by a White House reception at which the astronauts and other key project personnel are honoured by President Kennedy.

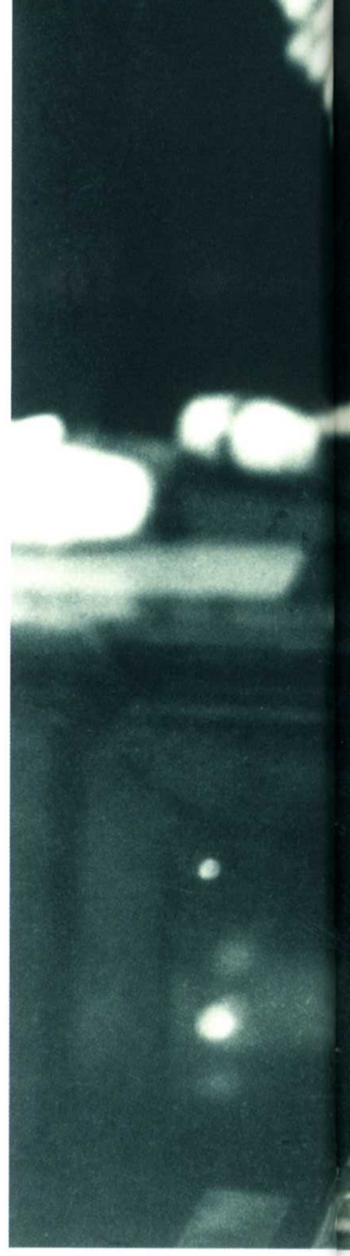


NOVEMBER 1967: TARGET MOON
The first of NASA's giant Saturn V rockets stands ready to launch the Apollo 4 test mission. Within two years similar rockets would launch men all the way to the Moon.

THE RACE TO THE MOON

THROUGHOUT THE 1960S, the Space Race became an outlet for all the Cold War rivalries that threatened to spill over into open conflict on Earth. Fully aware that the perception of Soviet superiority in space would have political repercussions around the globe, America's new, young President galvanized his nation with what seemed an insanely ambitious goal – to put American astronauts on the Moon by the end of the decade.

The challenge of a lunar landing was the endgame of the entire Space Race – the target lay at the very limits of 1960s technology, stretching the ingenuity and engineering skill of each side, while remaining tantalizingly achievable. Through the early stages, the rival powers continued an open race to each new spectacular, but cracks were starting to appear in the Soviet programme, and their lunar effort eventually fell apart in almost total secrecy. John F. Kennedy would not survive to see it, but America would live up to his challenge and eventually emerge as the ultimate victor in the Space Race.



20 January 1961
John F. Kennedy is inaugurated as President of the United States.

14 February 1961
James E. Webb is appointed as new NASA Administrator.

12 April 1961
Cosmonaut Yuri Gagarin makes his historic first flight into orbit.

14 April 1961
A meeting of top officials tells Kennedy that NASA's best chance of catching the Soviets is in the race to the Moon.

8 May 1961
Vice President Lyndon Johnson formally delivers to the President a set of recommendations on America's future in space, based on his discussions with Webb and others.

10 May 1961
Kennedy and his senior advisers ratify Johnson's recommendations.

25 May 1961
President Kennedy announces America's lunar ambitions in a speech to Congress.

Kennedy's challenge

With America soundly beaten in the early stages of the Space Race, in 1961 President Kennedy announced an ambitious programme to overtake the Soviet Union and land the first man on the Moon.

John F. Kennedy owed his presidency in part to the Space Race – he had turned early Soviet triumphs to his advantage, accusing Eisenhower's administration of complacency. His inauguration coincided with the arrival of a new administrator at NASA. In February 1961, James E. Webb took charge of both the agency and the Mercury programme. Hugh Dryden, former head of NACA, remained as his deputy. In addition, one of Kennedy's first acts as President was to establish a National Space Council, headed by Vice President Lyndon Baines Johnson.

BIOGRAPHY

DEKE SLAYTON

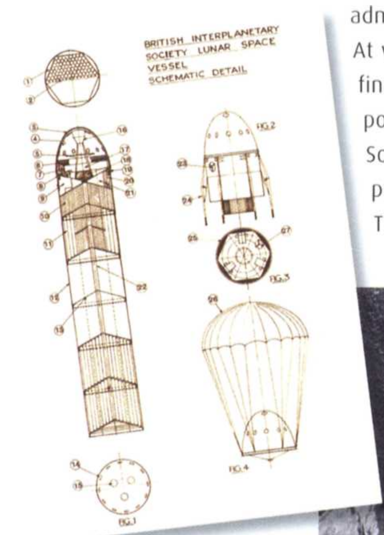
Donald K. (Deke) Slayton (1924–93) was the only one of NASA's original seven astronauts not to fly on a Mercury mission. Invalided out of the programme (and the Air Force) after the discovery of a heart irregularity, Slayton was soon in charge of NASA's Astronaut Office, where he was responsible for crew selection throughout the Gemini and Apollo programmes, demonstrating a deft ability to choose astronauts that worked well together. After a long period of treatment, he was passed fit for flight in 1973, and was able to select himself for the Apollo–Soyuz mission of 1975.

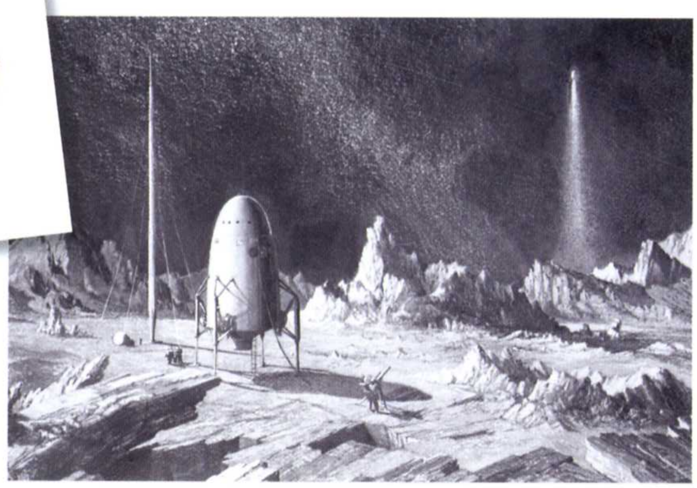
Racing for the Moon

Despite initial popularity, Kennedy's honeymoon with the American electorate ended within just a few months, amid a number of political setbacks including Yuri Gagarin's historic flight. Although Alan Shepard's forthcoming suborbital hop would help to restore American pride, it was clearly a poor retaliation to the Soviet achievement. Something had to be done that would focus the country's gaze on a more distant goal, allowing them to see past the immediate impression of Soviet space superiority. Just two days after Gagarin's flight, on 14 April, Kennedy summoned senior members of his administration and NASA to a policy meeting. At what point, Kennedy asked, might America finally manage to overtake its rivals? The power of Russian launchers meant that the Soviets would almost certainly be the first to put a multi-cosmonaut spacecraft into orbit. The same might go for any plans to launch a large, semi-permanent space station. When it came to the Moon, though, the competition seemed more balanced. While it was likely that a Soviet crew would be first to circle the Moon, the task of landing astronauts and returning them safely to Earth required so much new technology that the US would have a chance to catch up. If an all-out effort was made, the chances of an American being the first to set foot on the Moon were probably about fifty-fifty.

This was good enough for Kennedy, though details of the mission itself still had to be worked out. In early May, Johnson, Webb, and others met to draft a political justification of why America should race the Soviet Union to the Moon. This formed the basis for the President's historic announcement to Congress on 25 May, when he proclaimed: "I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth. No single space project in this period will be more impressive to mankind or more important for the long-range exploration of space; and none will be so difficult or expensive to accomplish."

THROWING DOWN THE GAUNTLET
Kennedy's commitment to space travel was more political than personal – he understood what it could mean to the American people in the midst of the Cold War. After his historic address to Congress, he soon found that the politicians on Capitol Hill agreed with him.





BRITISH VISION
In 1937, members of the British Interplanetary Society made a detailed study of how a manned lunar mission might be carried out. Their spacecraft designs bore a striking resemblance to Apollo.

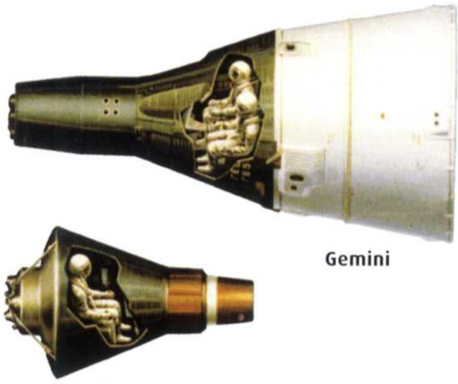
"We choose to go **to the Moon in this decade** and do the other things, not because they are easy, but **because they are hard ...**"

US President John F. Kennedy, Houston, Texas, 12 September 1962

EYES ON THE SKY
Wernher von Braun's rocket team would play a key role in the US Moon programme. Here von Braun explains his Saturn launch system to Kennedy in November 1963.

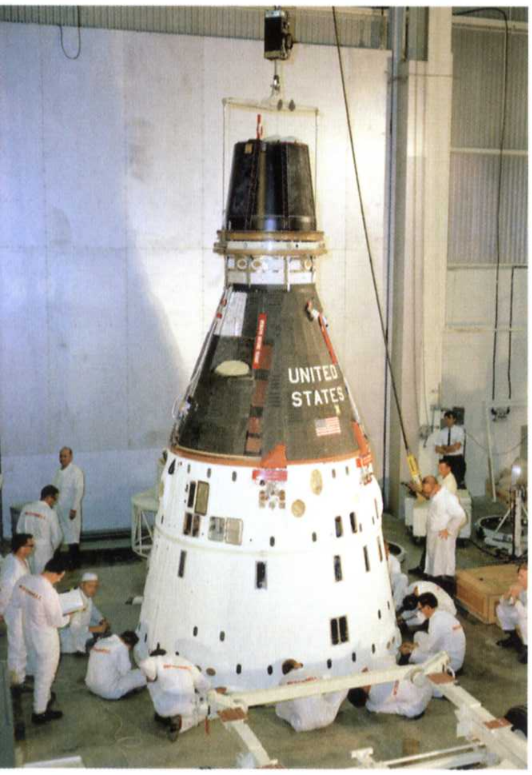
With such an ambitious goal ahead, NASA had to change priorities. Until now, the unspoken assumption had been that the exploration of space would roughly follow the template laid out by von Braun's *Colliers* articles of the mid-1950s, with colonization of Earth orbit as a prelude to the lunar voyage. Now there would be an all-out race for the Moon, and that would require new spacecraft and new skills. With the Mercury capsule relatively limited, an intermediate trainer spacecraft would be necessary – a vehicle that could be used for practising orbital manoeuvres, rendezvous and docking in space, and other techniques. This spacecraft would be called Gemini.

CAPSULES COMPARED
Although the Gemini re-entry module was the appropriate size for a two-man version of Mercury, it was only one element of a larger spacecraft, with a retrograde section and equipment module attached behind it.

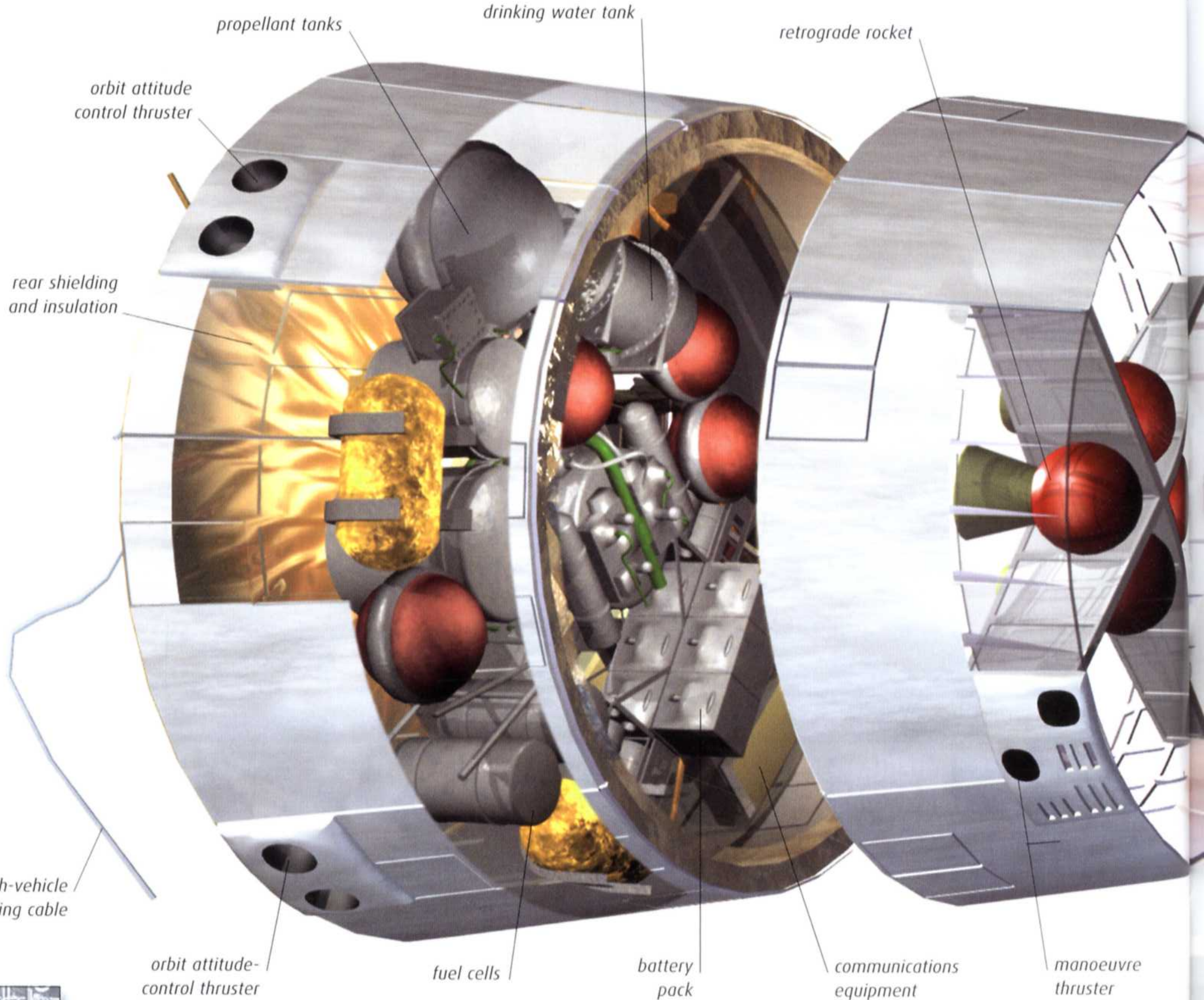


THE GEMINI SPACECRAFT
Gemini had three major sections: the re-entry module, the retrograde section, and the equipment module. While the crew were confined to the re-entry module, vital supplies of power and oxygen came from the equipment module. The retrograde module contained thrusters for changing orbit and retrorockets that were used to trigger re-entry.

CREW	2
LENGTH	5.6m (18ft 4in)
MAXIMUM DIAMETER IN ORBIT	3.05m (10ft)
MASS AT LAUNCH	3,763kg (8,297lb)
MASS AT LANDING	1,983kg (4,371lb)
ENGINES	4 x solid fuel retrorockets
MANUFACTURER	McDonnell Aircraft Corporation



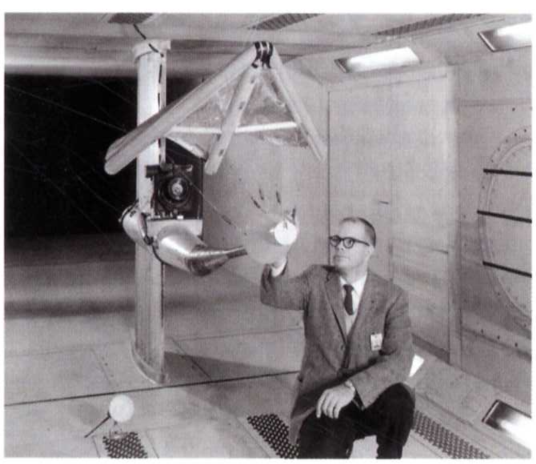
EASY MAINTENANCE
Hatches dotted all around the Gemini equipment module allowed components and consumables to be removed and replaced with ease.



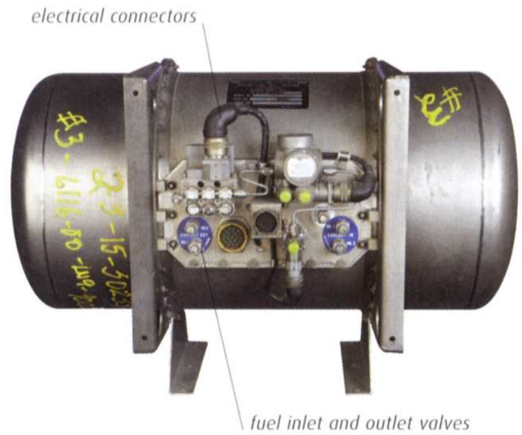
TECHNOLOGY
THE FIRST FLYING SPACESHIP

Gemini spacecraft

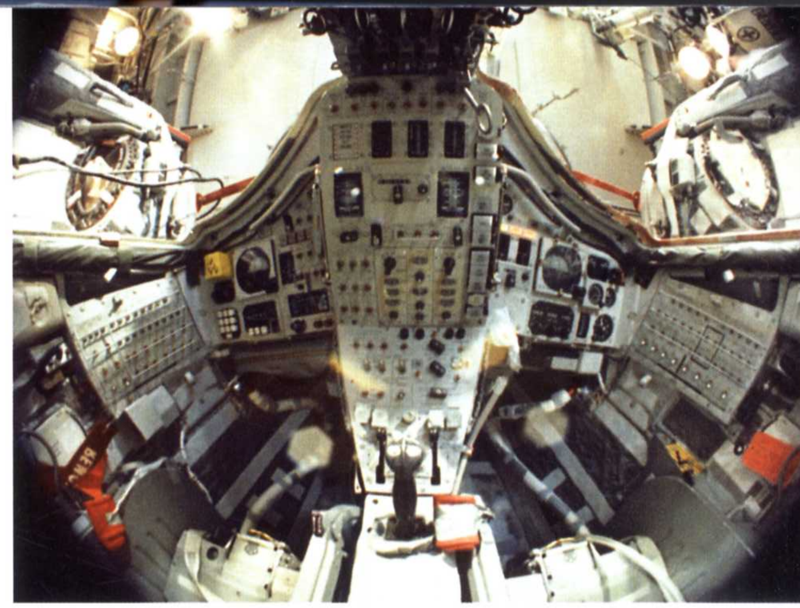
Gemini has been called the first true spaceship, because its revolutionary design allowed it to change orbits and actually "fly" in space, rather than just following the trajectory into which it was initially launched. It was also the first spacecraft with a docking capability. Conceived after Apollo, Gemini's design was in many ways more advanced than the spacecraft that succeeded it. Even after its last flight in 1966 Gemini had a long afterlife, with proposals for new projects based on the spacecraft continuing into the 1970s.



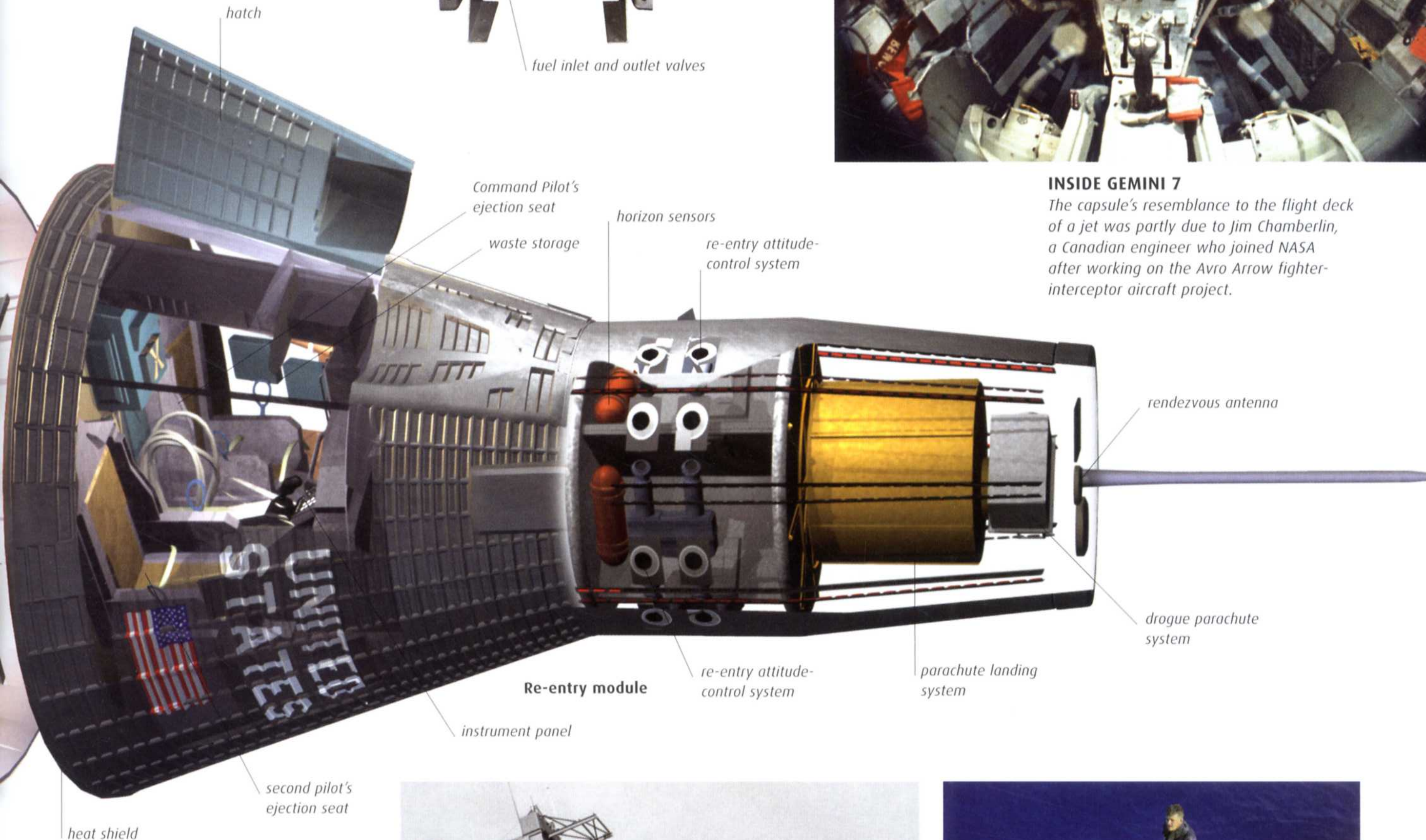
PARAGLIDER TEST
One early concept for Gemini would have seen it fly back to a ground-based landing beneath a glider called a Rogallo Wing. However, tests showed that the wing would not always deploy reliably, and so the concept was abandoned in favour of a splashdown.



GEMINI FUEL CELL
Gemini was the first spacecraft to use fuel-cell technology, which generated electricity by chemically combining hydrogen and oxygen to form water. This allowed it to operate for much longer than its predecessor.

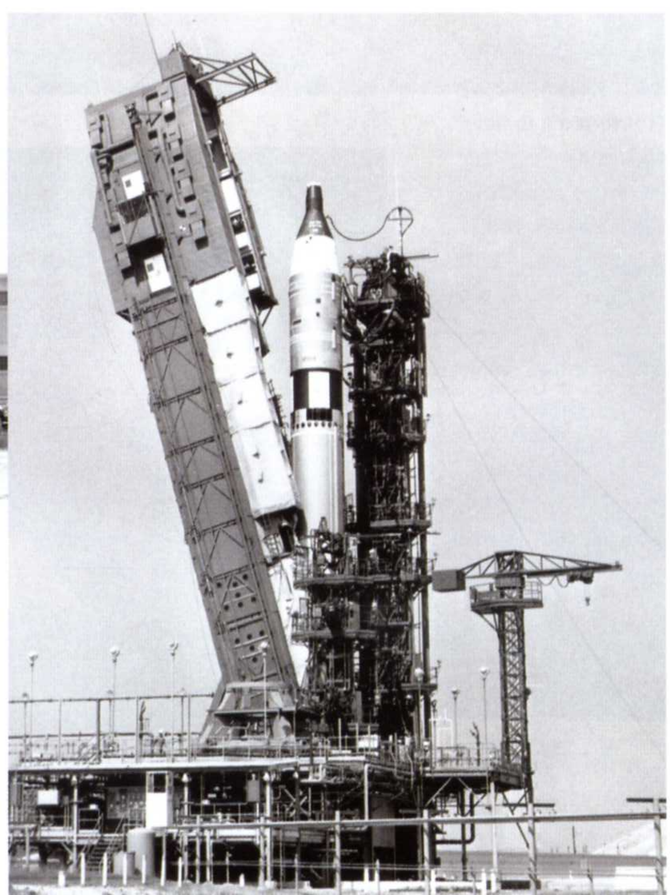


INSIDE GEMINI 7
The capsule's resemblance to the flight deck of a jet was partly due to Jim Chamberlin, a Canadian engineer who joined NASA after working on the Avro Arrow fighter-interceptor aircraft project.



Re-entry module

STACKING GEMINI 4
After the Gemini spacecraft arrived at Kennedy Space Center (above), it was stacked onto a Titan launch vehicle and raised using an erector tower. There was no escape tower on top of the capsule – unlike in Mercury and Apollo, Gemini astronauts would have used their ejector seats for emergency escapes.



RECOVERY AT SEA
Gemini was suspended from its parachute at two points, allowing it to splash down horizontally. The weighting of the spacecraft kept it upright in the water until the recovery crew arrived and attached a flotation collar.

Voskhod

After the announcement of the US Gemini project, Sergei Korolev was determined to maintain a Soviet lead in the Space Race. The result was Voskhod, a hurriedly modified and risky three-man spacecraft.

5 February 1964
During a tour of OKB-1 to review progress on the Soyuz spacecraft, Korolev surprises both cosmonauts and colleagues with his plans for a three-man version of Vostok.

13 March 1964
Development of the Voskhod project is approved by the Soviet government's Military–Industrial Commission.

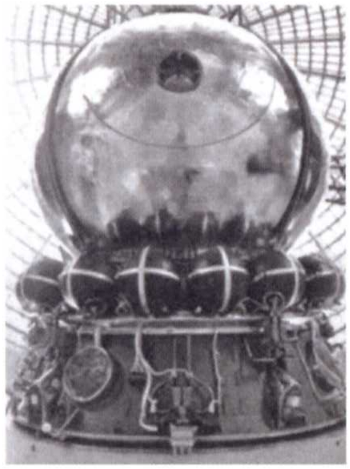
15 August 1964
Following testing of the landing systems, the Council of Chief Designers meets to approve Voskhod 1 as ready for spaceflight.

8 September 1964
A test drop of the Voskhod re-entry module from 10km (33,000ft) ends in a spectacular crash. Nevertheless, Korolev overrides the concerns of others about the retro-rocket system.

6 October 1964
A Voskhod test launch goes almost flawlessly. The capsule returns safely to Earth a day later.

12 October 1964
Voskhod 1 is launched from Baikonour on a day-long flight.

When the Gemini programme was announced in December 1961, it created a dilemma for Soviet politicians and engineers alike. The true successor to the Vostok capsules was Korolev's ambitious three-man Soyuz complex (see p.128), but this was still in the early stages of development, and the signs were that Gemini would certainly be ready long before it took flight. Faced with the prospect of losing the lead in the Space Race long before the final chase to the Moon, Korolev took a desperate gamble – one that would put the lives of his cosmonauts at more risk than ever before, but which would ultimately fool the watching world and maintain Soviet prestige. The Chief Designer apparently took the decision to develop a makeshift three-man capsule without consulting his superiors.



MINOR MODIFICATION
Externally, Vostok and Voskhod looked to be near-twins. Even the new retro-rockets were attached to the descent parachute rather than to the capsule.

Korolev's gambit

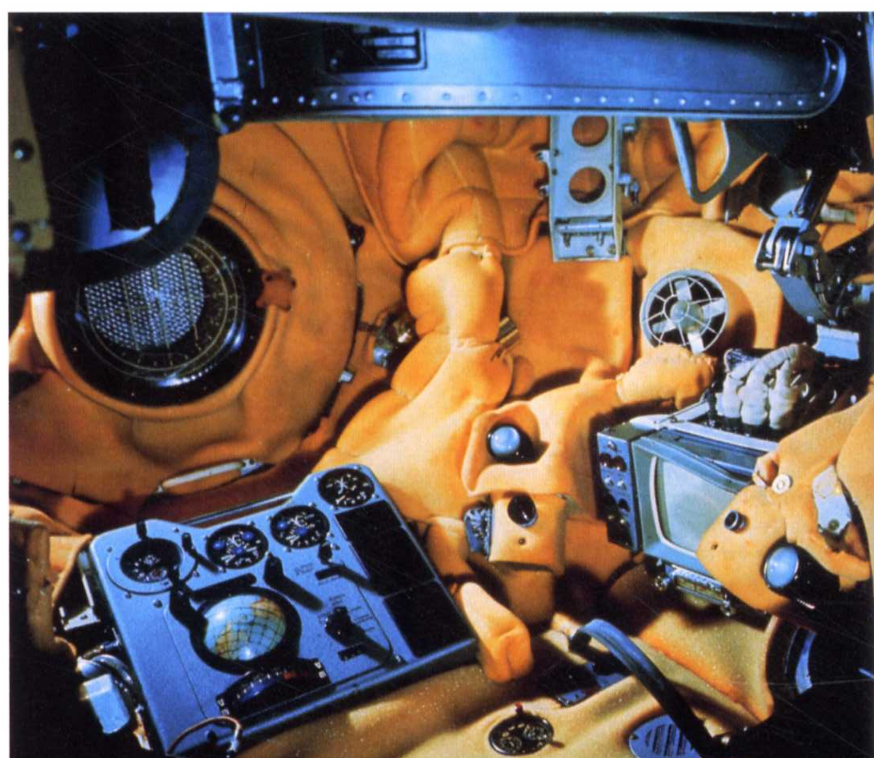
During a visit to inspect work on the Soyuz capsule in February 1964, Korolev announced to the assembled cosmonauts that there would be no more lone Vostok flights – instead the capsules already under construction would be converted into new configurations. One variant would squeeze three people into the cramped space, while the other would carry two cosmonauts in spacesuits and incorporate an airlock system allowing them to leave the spacecraft and float free in space.

The trade-offs needed to meet these requirements would make the flights much more risky for the cosmonauts – the ejector seat would be replaced by couches, and a new retro-rocket would have to slow the re-entry module's descent as it neared the ground, enabling the cosmonauts to land safely inside. Most dangerous of all, cosmonauts in the three-man capsule would not have room to wear spacesuits. Dressed instead in jumpsuits, they would have no protection from the vacuum of space if the capsule lost pressure. Several of Korolev's colleagues voiced doubts about the plan, including Kamanin. However, within a month the project had been given the go-ahead. Khrushchev was never told of the safety fears, but even if he had been, it is unlikely that a man with such an eye for the spectacular would have rejected the proposal.

Choosing the crew

Crew selection was a long process. At first Yuri Gagarin himself was to have commanded, but Kamanin was unwilling to risk a national hero on such a dangerous mission and Vostok 4 backup pilot Vladimir Komarov was finally selected. For the first time, Voskhod would allow people other than trained pilots into space. All agreed that sending a doctor into orbit would have benefits, while as an incentive to his engineers, Korolev decreed that one of them would have the chance to fly in the completed capsule. In the end, the successful candidates were medical specialist Boris Yegorov and engineer Konstantin Feoktistov.

Despite an overambitious initial target of a flight by August, Voskhod launched on 12 October 1964. The mission, which lasted for just over 24 hours, went relatively smoothly and provided the Soviets



INSIDE VOSKHOD
The small Vostok capsule was very cramped with three people aboard. Because the couches lay at right angles to the original ejector seat, the instruments were also hard to read.

with yet another propaganda coup. Carefully worded statements gave the impression that Voskhod was a major advance in spacecraft design, rather than the rush job that it was in reality, but the mission still provided useful insights into how a crew could work together in space. By the time America was ready to launch its first Gemini, a second Voskhod spectacular – the first spacewalk – was almost ready. Ironically, though, Korolev's great sponsor, Khrushchev, was in no position to crow about these new triumphs – even as Voskhod 1 circled the Earth, he was deposed in a coup, to be replaced by Leonid Brezhnev.

WELL-PADDED CELL
One concession to the risks of landing was the padding attached to every surface inside the capsule. However, in the event of a parachute or retro-rocket failure, it would have made little difference.

THE VOSKHOD THREE
The first Voskhod crew of test pilot Vladimir Komarov (left) and civilians Boris Yegorov (centre) and Konstantin Feoktistov (right) were able to send back some dramatic views of the Earth as seen from space (above).

Gemini takes flight

The early Gemini missions gave NASA its first experience of long-duration spaceflight. They also achieved a number of other American space firsts, paving the way for the more advanced later missions.

8 April 1964
A test launch puts an unmanned Gemini capsule into orbit, still attached to its upper rocket stage.

19 January 1965
An unmanned suborbital hop tests the capsule's performance during atmospheric re-entry.

23 March 1965
Gemini 3 carries Gus Grissom and John W. Young on three orbits around Earth.

3 June 1965
Gemini 4 launches, carrying James McDivitt and Ed White on a 62-orbit mission that includes the first American spacewalk.

7 June 1965
Gemini 4 returns safely to Earth.

21 August 1965
Gemini 5, with Gordon Cooper and Charles Conrad aboard, launches.

29 August 1965
Gemini 5's safe return from a record-breaking eight-day mission establishes the practicality of a mission to the Moon and back.

Gemini's journey from concept to completion took place at breakneck speed – the first test launch came on 8 April 1964, less than 30 months after the start of the programme. Gemini had to meet this timescale in order to fulfil its role as a bridge between the Mercury flights and the Apollo missions due to start in 1967.

Although the Gemini capsule resembled a scaled-up Mercury (the programme was originally named Mercury Mark 2), it marked a major leap forwards – it was perhaps the first true spaceship thanks to its ability to change orbits and manoeuvre in space.

First flights

The first test launch in 1964 was designed to check the spacecraft's function in orbit. In place of a crew, it carried instruments that sent back data on conditions during launch and in orbit. Gemini 1 was not designed for recovery, and so a second capsule was sent on a brief suborbital hop in January 1965 to assess re-entry conditions. By 23 March 1965, Gemini 3 was ready for the first manned launch.

Deke Slayton, now in charge of NASA's Astronaut Office, wanted to mix experienced astronauts with newer recruits. The first Gemini crew, therefore, were Gus Grissom (of *Liberty Bell 7* fame) and John W. Young. In a reference to his earlier misadventures, Grissom named the capsule *Molly Brown*, after a survivor from the "unsinkable" *Titanic* disaster. This was to be the last spacecraft named by its pilot.

Molly Brown's voyage proved less eventful than her namesake's – it lasted just three orbits, but during that time the astronauts were able to test their new engines and change their orbit in space for the first time. They also enjoyed a corned-beef sandwich that Young had smuggled aboard – much to the annoyance of mission control.

TECHNOLOGY

GEMINI'S TITAN LAUNCHER

All the Gemini missions were launched using Titan II rockets, derived from the US Air Force's Titan ICBM. This two-stage rocket, 33.2m (101ft) tall with the Gemini capsule in place, consisted of a first stage with dual rocket motors that burned a mix of unsymmetrical dimethylhydrazine (UDMH) and nitrogen tetroxide. The motors were relatively simple because this combination of fuel and oxidant is hypergolic – it combusts on contact, with no need for an ignition system. The second stage had a single engine burning the same fuel combination, and all three engines had gimbal-mounted exhaust nozzles that could be tilted to change direction.

Longer and further

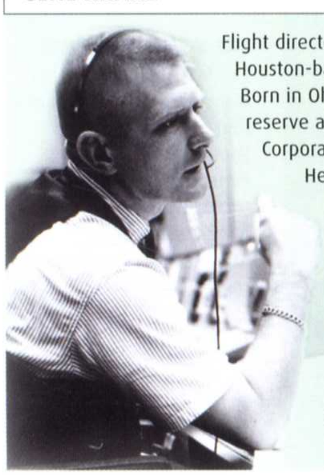
The second manned flight was far more ambitious. James McDivitt and Ed White stayed in orbit aboard Gemini 4 for more than four days, and White became the first American to walk in space (see over). The astronauts also carried out a variety of other experiments and attempted unsuccessfully to rendezvous with the spent upper stage of their Titan rocket.

Gemini 5, launched in August 1965, pushed the limits still further. New fuel cells allowed Gordon Cooper and Pete Conrad to remain in orbit for eight days, conducting various experiments. This flight also saw the debut of the crew-designed mission patch (see top left), though officials insisted the words "Eight days or bust" were removed in case the spacecraft had to be brought home early.

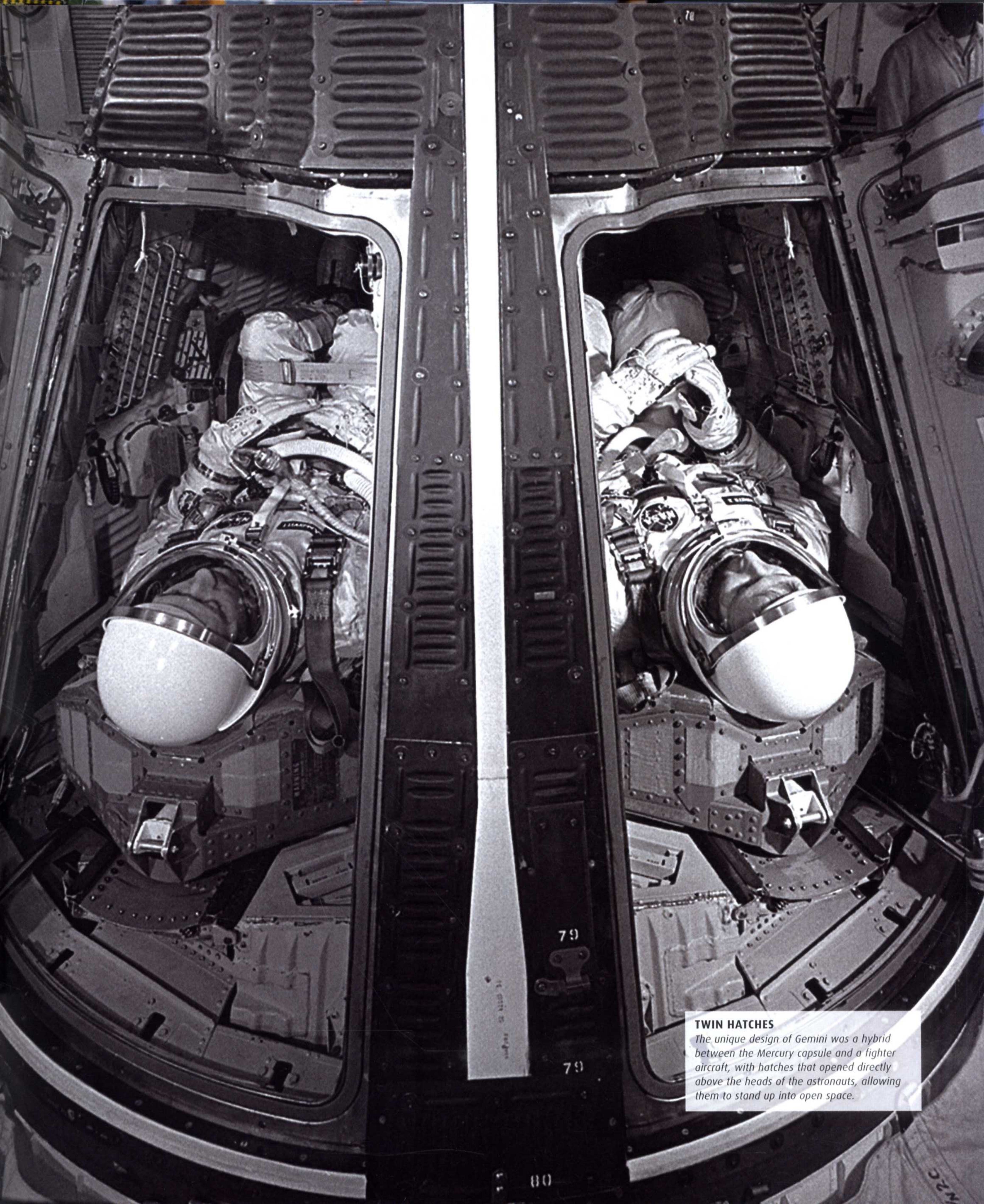
ENDURANCE FLIGHT
Command Pilot Pete Conrad is photographed by crewmate Gordon Cooper shortly after launch on their record-breaking eight-day mission aboard Gemini 5 in August 1965.

BIOGRAPHY

GENE KRANZ



Flight director Gene Kranz (b.1933) was in charge at NASA's new Houston-based Mission Control during many historic missions. Born in Ohio, Kranz trained as a fighter pilot in the USAF reserve after graduation, before joining the McDonnell Aircraft Corporation to work on surface-to-air missile development. He then joined NASA's Space Task Group and became procedures officer for the early Mercury flights, charged with ensuring the smooth transfer of power from Cape Canaveral's launch control to the Mercury control room. By the time of Gemini 4 he had been promoted to flight director (one of several who worked with a team of controllers on shifts throughout each mission). He became the best known of NASA's control staff thanks to his role in the Apollo 13 mission.



TWIN HATCHES

The unique design of Gemini was a hybrid between the Mercury capsule and a fighter aircraft, with hatches that opened directly above the heads of the astronauts, allowing them to stand up into open space.

SPLASHDOWN PRACTICE

John Young straddles a Gemini capsule while Gus Grissom looks on from a life raft during water egress training at Ellington Air Force Base, Texas. Grissom had experience of watery escapes from his Mercury days and at first wanted to name his Gemini 3 capsule Titanic *– an idea that was firmly vetoed by NASA officials.*

FLOATING FREE

Ed White's 15-minute spacewalk went more smoothly than Alexei Leonov's and was captured in stunning photographs by James McDivitt. However, the fuel supply in his manoeuvring gun soon ran out and he, too, had difficulties re-entering his spacecraft.

The first spacewalks

With future missions expected to become more complex, the time soon came to test the ability of astronauts and cosmonauts to operate in open space, beyond the confines of their spacecraft.

Sergei Korolev devised the idea of a two-man Vostok variant with an inflatable, detachable airlock at the same time as the three-man version used on Voskhod 1. Initially known as Vykhod (Exit), the mission's name was changed to Voskhod 2 at a late stage – the authorities felt the original name gave away the mission's purpose and could lead to embarrassment if the spacewalk did not go ahead.

SOVIET SPACEWALKER
The cramped design of Voskhod 2 meant that Pavel Belyayev's photographs of his crewmate Leonov were far less spectacular than the American images.

Four cosmonauts trained for the mission, but Alexei Leonov was always frontrunner for the first spacewalk. Pavel Belyayev was selected as the commander, remaining inside the craft throughout the mission. After numerous tests, including a fully automated launch and spacewalk by a suited dummy, Voskhod 2 launched from Baikonur on 18 March 1965. During the second orbit, the airlock inflated and Leonov made his way outside for a historic but ultimately nerve-shredding 12 minutes floating above the Earth (see over). The return to Earth did not go smoothly either – a failure of the main retro-rocket meant that Belyayev had to manually fire the backup on the following orbit, but the awkward cabin layout contributed to a 46-second delay and an overshoot of the original landing zone. To compound this, there was a repeat of the separation problems that plagued Vostoks 1 and 2. The capsule finally made a bumpy landing in the snowy forests of the Perm region, some 368km (229 miles) off target, and the cosmonauts had to spend a freezing night inside the spacecraft, surrounded by curious wolves, before rescuers on skis arrived the following day.

White walks in orbit

NASA's plans for Extra-Vehicular Activity, or EVA, were brought forward after the latest Soviet spectacular – astronaut Ed White would now leave the spacecraft during Gemini 4, in June 1965. Fortunately the Gemini design, with twin hatches above each of the astronaut couches, needed no modifications to allow for easy exit – the astronauts simply depressurized the cabin and opened White's hatch, allowing him to step out into space with none of the complexities of the Voskhod spacewalk. Although White, like Leonov, remained attached to the spacecraft by a tether, he took with him a hand-held "jet gun" that squirted pressurized gas from a nozzle, allowing him to push himself around until the fuel supply was exhausted.

White's EVA produced far more spectacular images than those from Leonov's spacewalk and helped NASA overcome the impression of trailing the Soviets yet again. Although no one knew it at the time, Leonov's spacewalk was to be the last Soviet spectacular – with Khrushchev ousted, the Voskhod project was cancelled, freeing the designers of OKB-1 to concentrate fully on the development of Soyuz.

BIOGRAPHY

ED WHITE

Born in Texas, Edward Higgins White (1930–67) was one of NASA's second astronaut group. After studying aeronautical engineering, he became a USAF pilot and later test pilot, before joining NASA. He was a star among his group and, having flown on Gemini 4, was scheduled to fly again on Gemini 10 but instead took a promotion to the Apollo 1 prime crew in 1967. He died with his crewmates in the fire that engulfed the Apollo 1 capsule during training (see pp.118–19).

"I'm **coming back** in … and it's **the saddest moment** of my life."

Ed White, on being told to re-enter the Gemini capsule, 3 June 1965

13 April 1964
The go-ahead is given to develop a two-man Vostok variant with an inflatable airlock, known initially as Vykhod.

24 September 1964
Khrushchev visits the Baikonur Cosmodrome to see a demonstration of the Vykhod EVA technique.

9 February 1965
Pavel Belyayev and Alexei Leonov are selected as prime crew for the renamed Voskhod 2.

22 February 1965
An unmanned test mission ends early after two ground stations send conflicting commands to the Cosmos 57 spacecraft.

18 March 1965
Voskhod 2 launches. On its second orbit, Alexei Leonov makes history's first spacewalk.

29 March 1965
A meeting of NASA officials chaired by Robert Gilruth decides that Ed White's planned stand-up EVA on Gemini 4 should be upgraded to a full, tethered spacewalk.

3 June 1965
Gemini 4 carries James McDivitt and Ed White into orbit, where White performs a spacewalk.

EXPERIENCE

THE FIRST SPACEWALK

ALEXEI LEONOV
Leonov's relaxed personality and sense of humour made him popular among the early cosmonaut trainees. During the Vostok 1 flight, Gagarin found time to send "regards to Blondin" – a reference to Leonov's fair hair.

Alone in the darkness

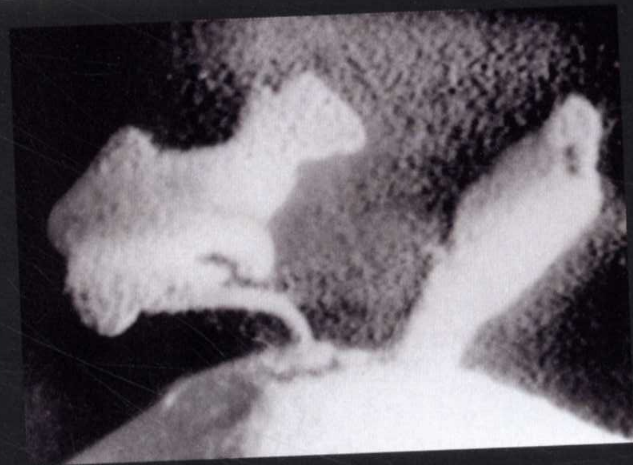
The flight of Voskhod 2 saw the first attempt by a cosmonaut to leave his ship and walk in orbit, protected only by a spacesuit. Although ultimately a triumph, Alexei Leonov's ten-minute foray into open space almost ended in disaster.

During Voskhod 2's second orbit around the Earth, Commander Pavel Belyayev began to inflate the Volga airlock. Meanwhile, Leonov had donned the backpack that would supply his suit with oxygen during the spacewalk. The suit itself was a modified version of the standard Vostok pressure suit, called Berkut (meaning "golden eagle"). The backpack blew oxygen into the suit, while a relief valve allowed air to vent into space, carrying carbon dioxide, heat, and moisture with it – a design feature that soon would prove vital. Leonov now climbed into the airlock while Belyayev sealed the hatch behind him and drained away the air, allowing his comrade to float out into open space, to the very limit of the 5m (16ft) cord that attached him to the spacecraft. As he later recalled:

"I was surprised that the Earth looked **very much like a globe or a map**, and that the Black Sea was really black – the darkest sea on Earth … I wondered who called the Black Sea 'black' and how did he know it? **I saw it from outer space!"**

While Leonov was delighted by the experience of floating free in orbit, he was already experiencing problems. The heat was intolerable, and the suit had inflated in the vacuum – Leonov was unable to reach the switch on his trouser leg that would have activated a high-quality Swiss camera mounted on his chest. The most difficult part of the spacewalk was just beginning.

INSIDE VOSKHOD
The Descent Module of the Voskhod was cramped with two astronauts in full spacesuits. Belyayev also wore a pressure suit in case something went wrong with the Volga airlock system.



FLOATING IN SPACE
Most of the pictures from Leonov's spacewalk (above and left) were grainy images transmitted from the television cameras – Leonov did not have a chance to retrieve film from the higher-quality camera mounted on the airlock. Leonov's daughter was frightened by the sight of her father alone in space, while his ageing grandfather criticized him for fooling around!

> "The Earth was **absolutely round** … I never knew what the word round meant until I saw Earth from space."

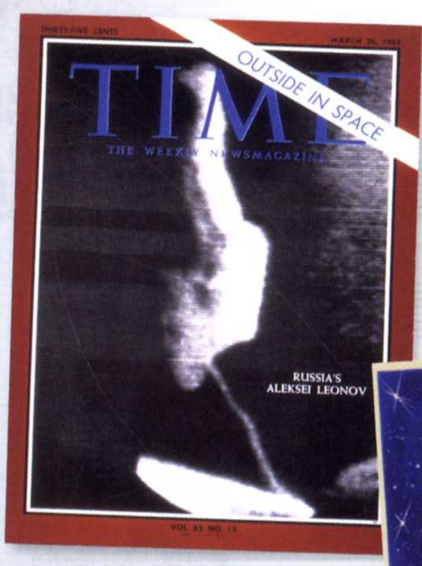
Alexei Leonov, 1980

After ten minutes in space, Leonov attempted to re-enter the airlock. The set procedure was to grip the airlock collar and push in feet first – but in the overinflated spacesuit, he found the gloves had ballooned away from his fingers and his feet had slipped out of his boots. Leonov tried to clamber in head first, but he could not fit into the airlock. The only solution was to open up the pressure relief valve and drain the suit of air.

> "… I had to take a decision to lower the pressure **inside the space suit**, but by how much? Too much would have led to a boiling of blood in the body, which would have finished me off. But I had to do it. I didn't report this **down to Earth**."

COMMEMORATION
Leonov's walk in space was heralded as a Soviet triumph on a par with the flight of Gagarin and was depicted in coins, medals, stamps and badges.

Once inside, he had to twist around in the narrow space to close the external hatch behind him so that the airlock could be repressurized. An exhausted Leonov re-entered the Voskhod capsule 20 minutes after leaving it.

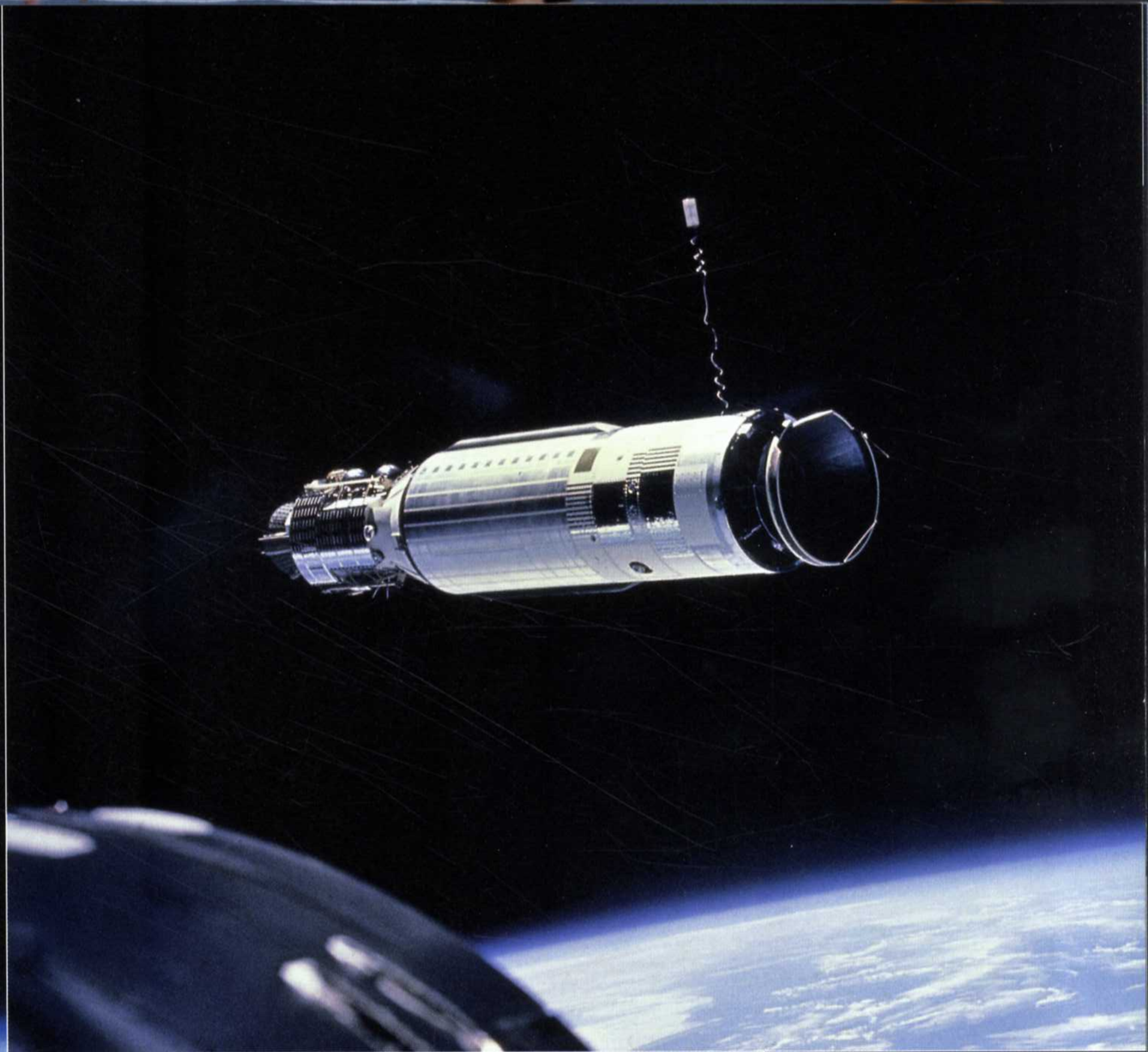


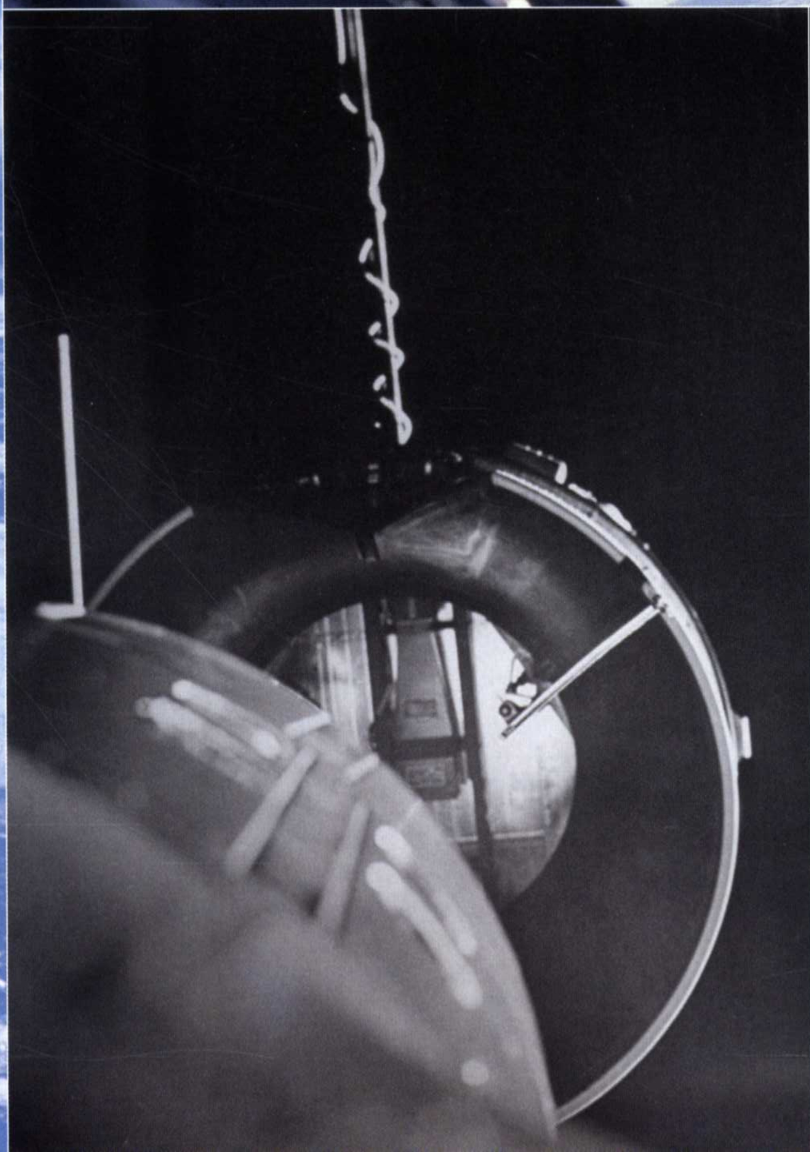
CELEBRATED EXPLOIT
The USA was gripped by Leonov's exploits – more so as his personality emerged at post-mission press conferences. NASA hurriedly added a spacewalk to its Gemini 4 mission.

> "Building manned orbital stations and exploring the Universe **are inseparably linked** with man's activity in open space."

Alexei Leonov, 1980

SOVIET HERO
A commemorative postcard shows Leonov floating like a superhero above the Earth – the truth of his struggle to re-enter the airlock did not emerge for several decades. Leonov has recently revealed he was also given a suicide pill in case he came adrift in space.





ABOVE THE EARTH
(Far left) Gemini 8's radar picked up the Agena ATV at a distance of 332km (206 miles), and the rocket stage was visible to the naked eye from 140km (87 miles). Neil Armstrong brought Gemini 8 in above the ATV so that he and David Scott could inspect its condition.

WEIGHTLESS WALTZ
(Above) After inspecting the ATV from a distance of 46m (150ft), Armstrong used Gemini 8's manoeuvring system to line up with the target vehicle, then edged towards it at a speed of 8cm (3in) per second.

READY TO DOCK
(Left) Finally, Gemini 8's nose cone edged into the ATV's docking adapter. The mechanism engaged first time – the first docking in space. But within minutes, Armstrong and Scott would be fighting for their lives as their spacecraft began to spin out of control.

Orbital ballet

23 August 1965
Gemini 5 practises a phantom rendezvous in orbit, after fuel-cell problems prevent rendezvous with its intended target.

25 October 1965
The planned launch of Gemini 6 is scrubbed after its Agena docking target fails to reach orbit.

4 December 1965
Gemini 7 successfully launches on a 14-day endurance mission for Jim Lovell and Frank Borman.

12 December 1965
The planned launch of Gemini 6 aborts due to an engine fault on ignition. Since the crew did not eject from the spacecraft, the launch can be rescheduled.

15 December 1965
Gemini 6A (previously Gemini 6) launches and makes a rendezvous with Gemini 7.

16 March 1966
Gemini 8 achieves the first successful space docking shortly after launch, but a malfunction brings the mission to a premature end.

Any practical plan to reach the Moon would involve rendezvous and docking in space. Rehearsing these manoeuvres was to be a key part of the later Gemini missions.

Simple fuel economics meant that the most direct route to the Moon – a launch directly from Earth of a spacecraft that could simply touch down in one piece on the Moon and carry enough fuel to blast off and return to Earth – was out of the question. NASA's mission planners came up with two practical alternatives (see p.117), but both would involve precision flying to bring together the parts of a lunar spacecraft in orbit.

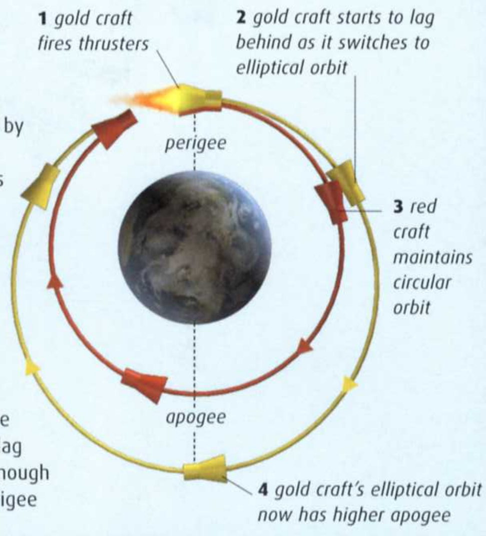
Early attempts

Early tests of Gemini's flight controls showed how much there was to learn. Gemini 3 proved that the capsule could change its orbit, but Gemini 4's attempts to catch up with its own discarded upper stage met only with frustration – as the capsule fired its thrusters, instead of catching up with the target, White and McDivitt found that they drifted into a higher orbit (see panel, right). Gemini 5 released a small pod into a different orbit to use for target practice, but a fuel cell problem meant that the crew could not risk wasting energy to catch it. Fortunately Buzz Aldrin, a trainee astronaut and orbital mechanics expert, came up with a new test – a phantom rendezvous in which Gemini 5 flew to a precise point without burning excessive energy.

TECHNOLOGY

SWITCHING ORBITS

Changing orbits in space is simply a matter of firing engines to either slow down or speed up the spacecraft. In the example shown here, two spacecraft start out side by side in a circular orbit around the Earth. The gold craft briefly fires its thrusters, but instead of moving faster in its existing orbit, it is pushed into an elliptical orbit, with a higher apogee (the point in the orbit furthest from Earth). The further a spacecraft is from the object it is orbiting, the slower it moves, and this, combined with the greater distance it travels, causes the gold craft to lag further and further behind, even though both craft still have a common perigee (the point closest to Earth).



Dual flights

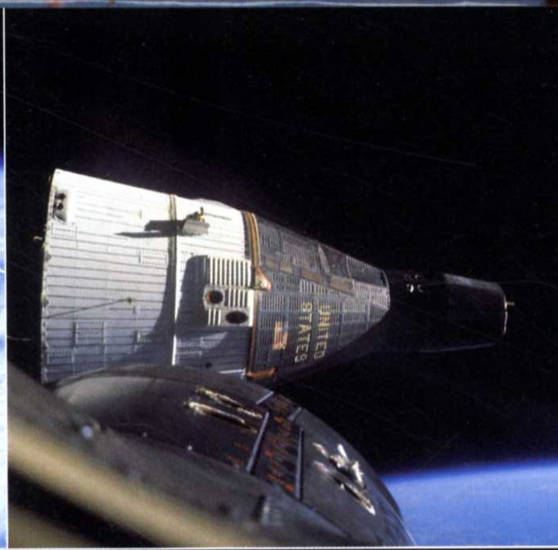
The next plan was to rendezvous with an unmanned Agena Target Vehicle or ATV (an adapted rocket stage) that had already been launched into orbit. This was to have been the mission of Gemini 6, but even as Walter Schirra and Thomas Stafford sat in their Titan rocket on 25 October 1965, ready to chase their target into orbit, the ATV launcher exploded and the mission had to be scrubbed.

HISTORY FOCUS

IN A SPIN

Shortly after Gemini 8 docked with its ATV (see p.106) the crew of David Scott (left) and Neil Armstrong faced a serious problem, as a jammed thruster set the joined spacecraft spinning rapidly. Separating from the ATV only made the problem worse, and Armstrong had no choice but to shut down the thruster system and fire the re-entry engines to stabilise the spacecraft. The plan worked, but it brought the spacecraft back to an emergency splashdown just 10 hours after launch.

MEETING IN SPACE
Schirra and Stafford took this photograph of Gemini 7 as their own Gemini 6A capsule flew towards the first fully controlled orbital rendezvous. Gemini 7 had already been in orbit for 11 days.

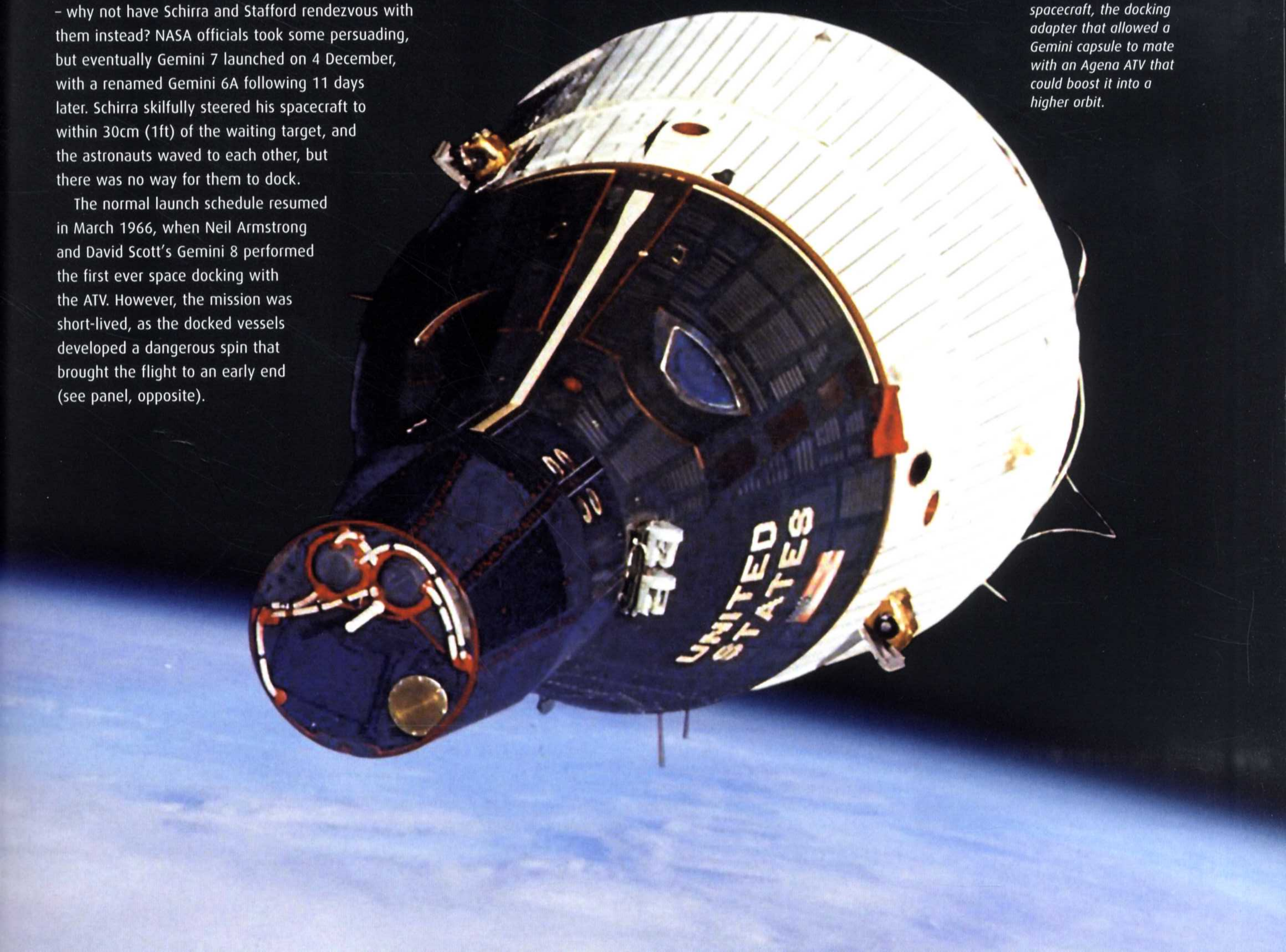


CLOSING IN
At their closest approach, the Gemini spacecraft were so close that the astronauts could communicate by holding handwritten signs up to the windows of their capsules, 260km (160 miles) above the Earth.

SEEING IS BELIEVING
During their closest approach, Jim Lovell, aboard Gemini 7, asked, "How's the visibility?". "Pretty bad," replied Walter Schirra on Gemini 6A, "I can see through the window and see you fellows inside!"

Frank Borman and Jim Lovell, whose Gemini 7 mission was intended largely as a two-week space-endurance test, now made an audacious suggestion – why not have Schirra and Stafford rendezvous with them instead? NASA officials took some persuading, but eventually Gemini 7 launched on 4 December, with a renamed Gemini 6A following 11 days later. Schirra skilfully steered his spacecraft to within 30cm (1ft) of the waiting target, and the astronauts waved to each other, but there was no way for them to dock.

The normal launch schedule resumed in March 1966, when Neil Armstrong and David Scott's Gemini 8 performed the first ever space docking with the ATV. However, the mission was short-lived, as the docked vessels developed a dangerous spin that brought the flight to an early end (see panel, opposite).



GEMINI 6A IN ORBIT
A head-on view of Gemini 6A from Gemini 7 reveals the "business end" of the spacecraft, the docking adapter that allowed a Gemini capsule to mate with an Agena ATV that could boost it into a higher orbit.

Learning to fly

The final phase of the Gemini programme saw a series of increasingly ambitious flights, dockings, and EVAs as America's astronauts geared up for the coming Apollo missions.

28 February 1966
The planned Gemini 9 crew, Elliott See and Charles Bassett, are killed when their T-38 jet crashes.

17 May 1966
Gemini 9's Agena ATV fails to reach orbit.

1 June 1966
The Augmented Target Docking Adapter (ATDA), a new target for Gemini 9, is launched.

3 June 1966
Gemini 9A launches to a rendezvous with the ATDA, but docking is not possible.

18 July 1966
Gemini 10 is launched and docks successfully with its ATV.

20 July 1966
Gemini 10 makes a second rendezvous, with the abandoned Gemini 8 ATV.

12 September 1966
Gemini 11 launches and docks successfully with its ATV, setting a new world altitude record.

15 November 1966
Gemini 12 successfully splashes down.

Even before launch, Gemini 9 was cursed by bad luck – the original crew of Elliott See and Charles Bassett died in February 1966 when their plane crashed in fog while attempting to land at the McDonnell plant in St. Louis, Missouri, where their spacecraft was under construction. As a result, the backup crew of Thomas Stafford and Eugene Cernan took their place.

The mission plan involved a rendezvous with an Agena ATV, but as had happened before, the target vehicle failed to reach orbit. A replacement was built and launched in just two weeks, and the Gemini mission (renamed 9A to indicate the use of a backup crew) flew to meet it two days later, on 3 June. The rendezvous went perfectly, but the astronauts discovered that the shroud around the target vehicle had not separated properly, and so docking would be impossible. Nevertheless the mission continued, with the crew practising a variety of manoeuvres in orbit.

The capsule carried with it a prototype Astronaut Manoeuvring Unit (AMU), or rocket pack, to aid astronauts in orbit. The intention was for Cernan to test the device, but it had been mounted on the hull near the back of the spacecraft, and Cernan's efforts to reach it were hampered by a lack of handholds. When he did get there, he discovered that donning the AMU would mean severing his main tether to the cabin, and he would probably be unable to re-attach it. In the end, an exhausted Cernan, his visor steamed up by his exertions, decided that it was too risky. He returned to the capsule after a 128-minute spacewalk, the mission incomplete but with many lessons learned.

Geminis 10 and 11

Fortunately, Cernan's misadventure was the last major setback for Gemini. Little more than a month later, Gemini 10, crewed by John Young and Michael Collins, achieved a very successful double rendezvous – docking first with their own ATV and then using its engines to boost their orbit for a close rendezvous with the ATV abandoned during Gemini 8. Collins was even able to spacewalk across to the dormant vehicle.

Gemini 11, launched on 12 September 1966, was also a success. Pete Conrad and Richard Gordon were able to dock with their booster just 85 minutes after launch, and Gordon made a spacewalk to attach a tether from the Gemini capsule to the Agena, before they propelled themselves to a new record altitude of 1,374km (854 miles). As they returned to a lower orbit, they undocked from the ATV so that the two spacecraft began to spin around their common centre of mass. The result was a weak form of artificial gravity for the two astronauts.

Last hurrah

The final Gemini mission was the most ambitious of all, and fortunately a great success. After a series of delays caused by spacecraft glitches, Buzz Aldrin and Jim Lovell ascended to orbit on 11 November 1966. Their four-day mission was a dry run for many of the techniques needed for Apollo, and they practised docking and undocking the ATV, and manoeuvring with it attached. Plans to use it to boost them into a higher orbit had to be abandoned, however, because of concerns over the ATV's condition after launch. Perhaps the most important achievements of the mission were Aldrin's EVAs. Extra grips had been fitted to the capsule to help with weightless manoeuvres, and Aldrin was able to spend over two hours on the end of an umbilical tether, carrying out various tests and finally proving that an astronaut could perform useful work outside a spacecraft.

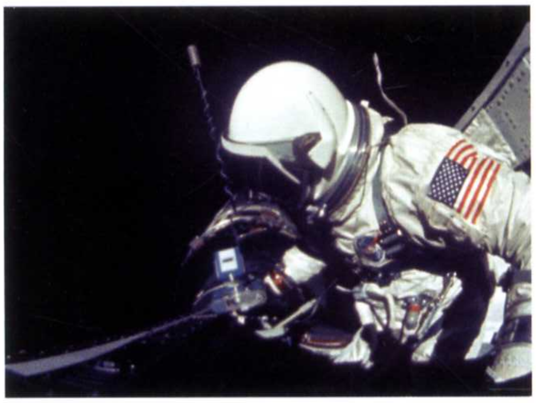
ADAPTER IN ORBIT
The Augmented Target Docking Adapter (ATDA) designed for Gemini 9 floats high above the Earth, its shrouding still half-attached. This unusual view of the device led to Thomas Stafford's memorable comment, likening it to an "angry alligator".

THWARTED PLANS
As Gemini 9A came in sight of the hastily launched ATDA docking target, Thomas Stafford exclaimed "Look at that moose!" The protective shroud was frustratingly close to coming free, but edging the Gemini capsule's nose into the open end was too risky.

RIDING HIGH
Astronaut Dick Gordon of Gemini 11 straddles the Agena ATV, while attaching the tether that would later be used to generate the first artificial gravity in space.

"It looks like an **angry alligator** out here rotating around."

Gemini 9A astronaut Thomas Stafford describes the defective target vehicle, 3 June 1966



STAND-UP EXPERIMENTS
Gemini 12's first EVA lasted for just under two-and-a-half hours and was a stand-up – Buzz Aldrin stood up in the capsule's hatch and performed various experiments, as well as setting up ultraviolet and movie cameras.

PARTICLE COLLECTOR
Here Aldrin is retrieving a micrometeorite collector. The device was used to collect small particles drifting through Earth orbit. These were later analyzed for signs of any organisms capable of living in space.

FLOATING FREE
During his second EVA, Aldrin floated free, tethered to his spacecraft by an umbilical line. Here, he is conducting experiments at a workstation attached to the ATV and taking photographs of star fields.

1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010

23 August 1961
Ranger 1, an ill-fated engineering test for NASA's series of lunar crash-landers, fails to reach its intended orbit around the Earth.

26 January 1962
Ranger 3, the first of the Ranger probes intended for the Moon, is launched but misses its target completely.

31 July 1964
Ranger 7 becomes the first successful probe in the series, sending back pictures right up to its impact with the Moon.

2 June 1966
Surveyor 1 touches down in the Oceanus Procellarum – the first successful soft-landing on the Moon.

10 August 1966
Lunar Orbiter 1 is launched into orbit around the Moon, the first of five mostly successful orbiter probes that capture details on the lunar surface as small as 2m (6ft) across.

31 January 1968
Lunar Orbiter 5 crashes onto the Moon after a successful mission.

Surveying the Moon

To pave the way for Apollo, NASA embarked on an ambitious programme of lunar discovery. This involved three different series of spaceprobes – Rangers, Surveyors, and Lunar Orbiters.

When President Kennedy announced America's lunar ambitions in May 1961, the closest thing to a successful moonshot achieved by NASA had been Pioneer 4's relatively near miss in March 1959 (see p.52). The Moon still held many mysteries – and while some were scientific puzzles of interest mainly to astronomers, others might have a direct bearing on any expedition attempting to land there.

For example, were the Moon's plentiful craters volcanic or formed by impacts from space? If they were volcanic, would there still be seismic activity on the Moon? If they were caused by impacts, then would the surface be stable, or so badly pulverized that it could not support the weight of a spacecraft?

Automatic probes

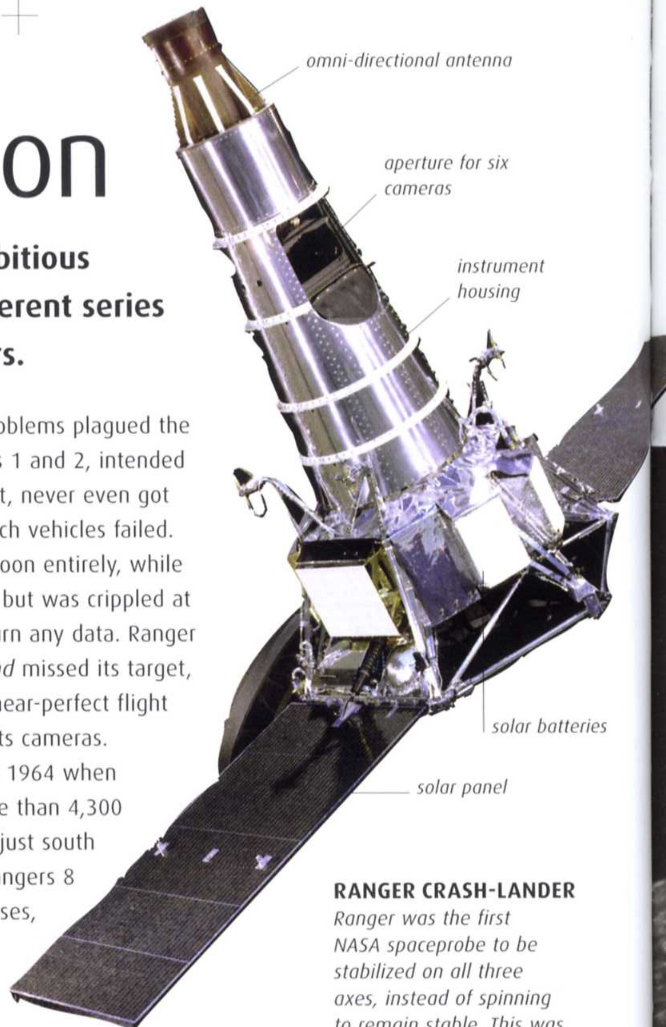
In order to answer these questions, NASA developed three series of automatic probes, each of which would add more to our understanding of the Moon and help to answer some of the questions that still hung over the Apollo programme. The first of these were the relatively unambitious Rangers. These were succeeded by the more accomplished Surveyors and Lunar Orbiters.

The aim of the Ranger programme, which began in Jaunuary 1961, was to crash-land probes on the Moon, sending back photographs up to the moment of impact. However, problems plagued the early launches. Rangers 1 and 2, intended for testing in Earth orbit, never even got that far after their launch vehicles failed. Ranger 3 missed the Moon entirely, while Ranger 4 hit its target, but was crippled at launch and did not return any data. Ranger 5 was both disabled *and* missed its target, while Ranger 6 had a near-perfect flight except for a failure of its cameras.

Things came right in 1964 when Ranger 7 returned more than 4,300 pictures before impact just south of Copernicus crater. Rangers 8 and 9 were also successes, crashing in the Sea of Tranquillity and the Alphonsus crater respectively. They gave a good look at the lunar surface and solved a mystery – some of the Moon's craters were so small that they could only be the result of asteroids collisions.

Soft-landers and orbiters

The far better success rate of the more ambitious Surveyors and Lunar Orbiters shows how much NASA learned during the early 1960s. The Surveyors were



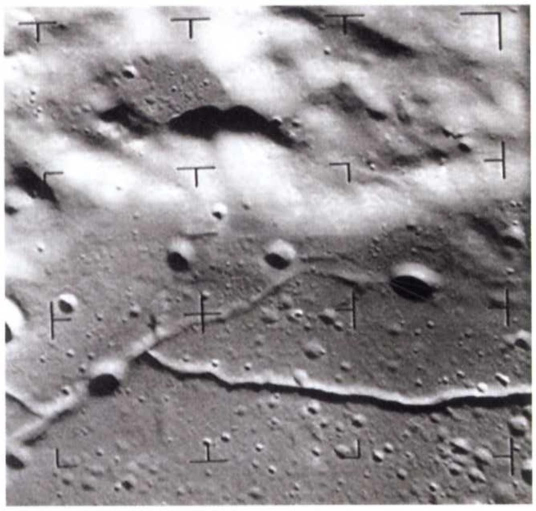
RANGER CRASH-LANDER
Ranger was the first NASA spaceprobe to be stabilized on all three axes, instead of spinning to remain stable. This was achieved by imparting small amounts of thrust from nitrogen gas jets. This allowed the use of large flat solar panels tilted toward the Sun, instead of the earlier spinning drum design, and produced a large increase in electrical power to the probe.

Ranger 7 – 31 July 1964

When Ranger 7's cameras were activated during its final approach to the Moon, they returned this image – the first picture of the Moon from a US spacecraft.

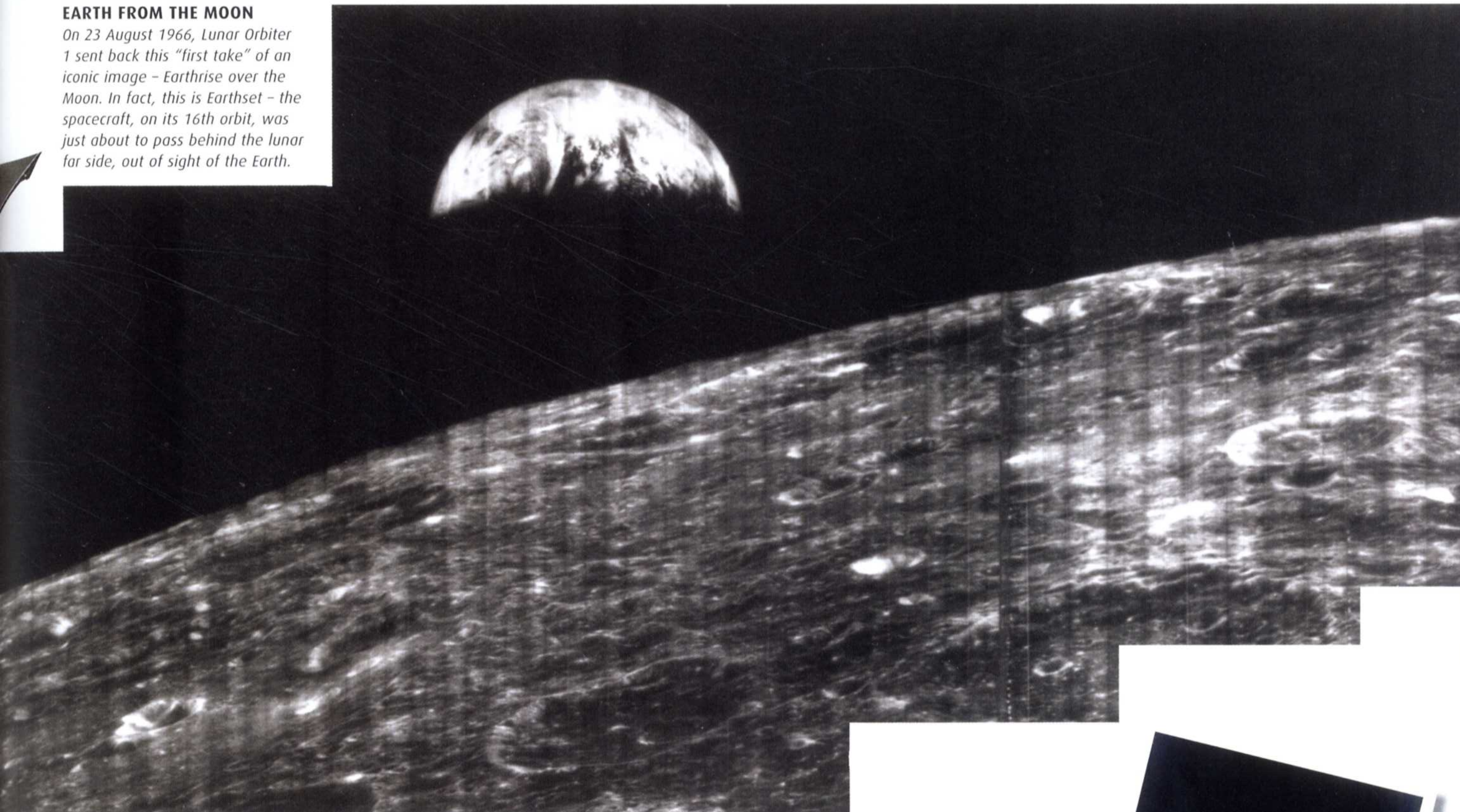
Ranger 7 – 31 July 1964

From an altitude of 1,335km (829 miles), just over eight minutes from impact, Ranger 7 returned this image of Guericke, a battered impact crater 63km (39 miles) across.



Ranger 9 – 24 March 1965

Television audiences received live pictures as Ranger 9 plunged into the crater Alphonsus. From 650km (400 miles) up, lava channels were clearly visible on the crater floor.



EARTH FROM THE MOON
On 23 August 1966, Lunar Orbiter 1 sent back this "first take" of an iconic image – Earthrise over the Moon. In fact, this is Earthset – the spacecraft, on its 16th orbit, was just about to pass behind the lunar far side, out of sight of the Earth.

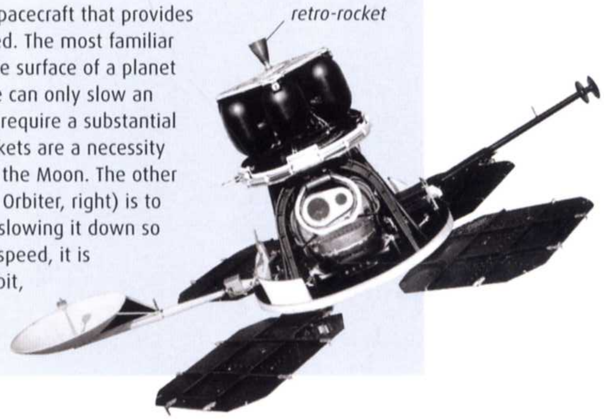
designed to make soft landings in targeted areas of the Moon and send back data about lunar conditions. Surveyor 1 touched down in the Sea of Storms on 2 June 1966. To everyone's relief, it did not sink without trace, but instead sent back images and data about the Moon's surface chemistry. Six more Surveyors followed over the next 20 months, with only two failures – Surveyors 2 and 4, both of which crash-landed.

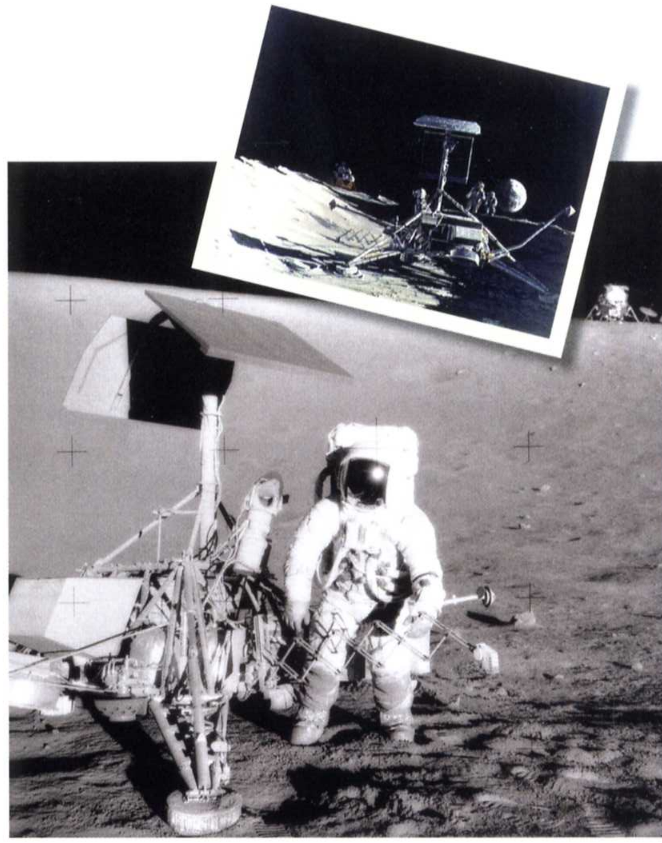
In parallel with the Surveyors, NASA launched a series of five Lunar Orbiters, spacecraft that would become satellites of Earth's own satellite. Placed in different orbits around the Moon, the first three concentrated on imaging possible landing sites for the Apollo missions, while the last two completed a broader scientific survey that saw 99 per cent of the Moon's surface, on both near and far sides, mapped at relatively high resolution.

TECHNOLOGY

RETRO-ROCKETS

A retro-rocket is an engine attached to a spacecraft that provides a retrograde (decelerating) force when fired. The most familiar use of retro-rockets is during descent to the surface of a planet or a moon. Parachutes of a reasonable size can only slow an object's descent by a certain amount, and require a substantial atmosphere to generate drag, so retro-rockets are a necessity for soft landing on an airless body such as the Moon. The other main use of retro-rockets (as on the Lunar Orbiter, right) is to modify a spacecraft's trajectory – perhaps slowing it down so that, instead of flying past a body at high speed, it is caught up by its gravity and pulled into orbit, or slowing it further, so that it drops out of orbit towards a landing site.



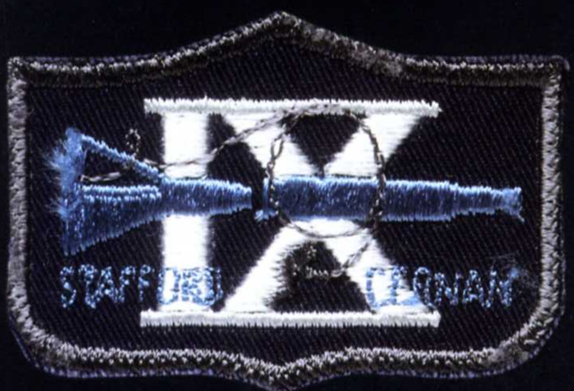


VISITORS FROM EARTH
In November 1969, the astronauts of Apollo 12 landed within walking distance of Surveyor 3 in the Sea of Storms and inspected it to see how it had fared during 30 months on the Moon.

Gemini 6

Gemini 5

Gemini 8



Gemini 9

Gemini 10

Apollo 7

Apollo 8

Apollo 9

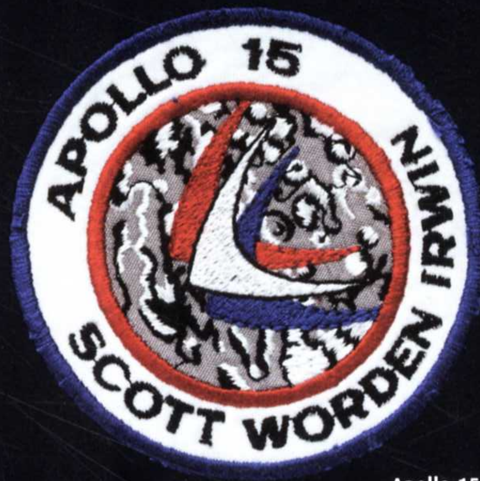
Apollo 10

Apollo 11

Apollo 12

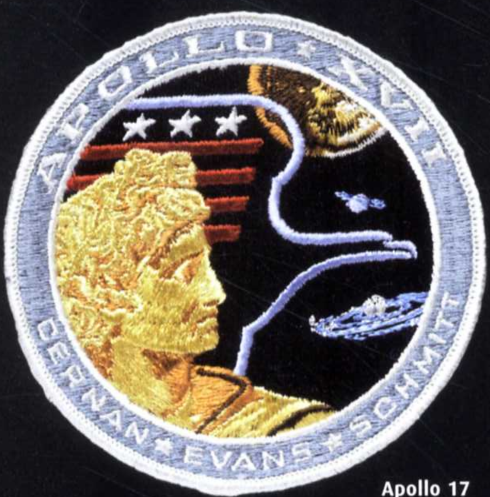
Apollo 13

Apollo 14



Apollo 15

Apollo 16



Apollo 17

NASA mission patches

The familiar patches used to identify NASA missions did not exist in the Mercury era, but the patches from Gemini and Apollo onwards provide a colourful chronicle of the American adventure in space.

The first mission patch came about at the direct request of the Gemini 5 crew. After the fuss about Gus Grissom wanting to name Gemini 3 *Molly Brown* (see p.82), NASA decided it would no longer allow astronauts to name their spacecraft. Gordon Cooper felt strongly that the astronauts should put some kind of personal stamp on each mission and submitted an aviation-inspired handmade "mission patch" to NASA Administrator James Webb. The idea was approved, but on the condition that the words "8 days or bust" were covered up – NASA did not want to tempt fate or snide remarks from the media if the flight failed to last for its intended duration.

Throughout the Gemini and Apollo missions, astronauts tackled the prospect of designing their patches with enthusiasm – sometimes recruiting family members to help, sometimes working with official NASA artists. Among the most striking is the Apollo 8 patch, sketched up by Jim Lovell during a flight with Frank Borman shortly after they had learned their mission would be the first around the Moon. From Apollo 9 onwards, the need to distinguish between the LM and CSM meant that astronauts were once again allowed to name their spacecraft. The later Apollo patches often reference the spacecraft names – most notably on the famous Apollo 11 Eagle patch. The elegant Apollo 15 patch was designed by Italian dress designer (and former aeronautical engineer) Emilio Pucci, at the special request of the crew.

The post-Apollo patches tended to be based on ideas that came from NASA centres, which were then selected and tweaked at the request of the crew. Curiously, the Skylab patches are wrongly numbered – they ignore the fact that Skylab 1 was actually -the station's unmanned launch.

Apollo–Soyuz

Skylab 1 (2)

Skylab 2 (3)

Skylab 3(4)

Planning Apollo

In the wake of President Kennedy's monumental announcement, NASA's experts turned their attention to working out how they would turn Project Apollo into a reality.

September 1960
John C. Houboult begins lobbying within NASA to promote the advantatges of lunar orbit fendezvous for a manned Moon mission.

27 October 1961
A test of the Saturn I launch vehicle marks the first launch of the Apollo programme.

21 December 1961
NASA selects the Saturn C-5 as its Moon rocket. In the preceding days, contracts have been awarded for construction of various stages.

6 February 1962
Robert Gilruth and the Space Task Group conclude that an LOR mission is the best way to reach the Moon.

7 June 1962
Wernher von Braun backs an LOR mission.

11 July 1962
James Webb announces NASA's decision to base Apollo around an LOR mission profile.

7 November 1963
Pad Abort Test 1 sees the first test of a boilerplate Apollo CSM.

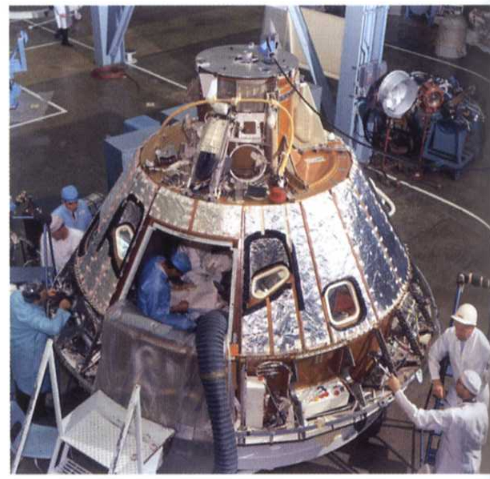
The challenge of putting a spacecraft on the Moon and returning it safely was not a trivial one, and the first decision that had to be made was precisely how NASA would get there. Three clear options soon emerged, each with its own advantages and disadvantages. These were direct ascent (DA), Earth orbit rendezvous (EOR), and lunar orbit rendezvous (LOR) (see illustration, opposite).

While direct ascent was the simplest approach, it required far more fuel than the other options and would involve the construction of truly monstrous rockets, so large that their construction and testing would almost certainly push the project past its 1969 deadline. The choice therefore narrowed down to the two options that involved in-flight docking and separation. EOR kept these delicate exercises in the relative safety of Earth orbit, but it also involved taking a large fuel-laden spacecraft down to the lunar surface. LOR shifted the in-flight manoeuvres away from the Earth, and risked stranding the astronauts, but it considerably reduced the size of the lunar lander required. In the end, the LOR advocates, led by John C. Houboult of Langley Research Laboratory, won the vital backing of Wernher von Braun for their approach, and in July 1962 the decision to go with an LOR mission was formally approved.

Rockets for the Moon

More debate surrounded the choice of rocket that would take Apollo to the Moon. NASA was already developing its own massive launcher, called Nova, when von Braun's ABMA team formally joined the organisation. The Huntsville group brought with them plans for a heavy-lift launcher called Saturn.

The vehicle's first stage was already being tested, and plans for the upper stages were well developed, so a NASA committee was established to evaluate them, under experienced engineer Abe Silverstein. They recommended a variety of configurations, including a giant called the Saturn C-5. NASA ultimately decided that this rocket (later known as the Saturn V) would be easier to get into production by the deadline than their own Nova. Since the Moon rocket itself would not be ready for several years, they would also develop the Saturn C-1 (later Saturn I), a simpler variant more reliant on existing technology, for testing lunar spacecraft hardware in Earth orbit. Von Braun was delighted – his team at Huntsville's newly established Marshall Space Flight Center would be at the heart of the US lunar effort.



UNDER CONSTRUCTION
Technicians at North American Aviation's factory in Downey, California, prepare to fit the heat shield to the Command Module of Apollo CSM 012, the module that should have hosted Apollo 1.

SATURN I CLUSTER
The lower stage of a Saturn I, seen here being unloaded from its transport barge, reveals its secret – the basis of von Braun's first Saturn rocket was in fact a cluster of eight Redstone rockets surrounding a central Jupiter, each with improved engines.

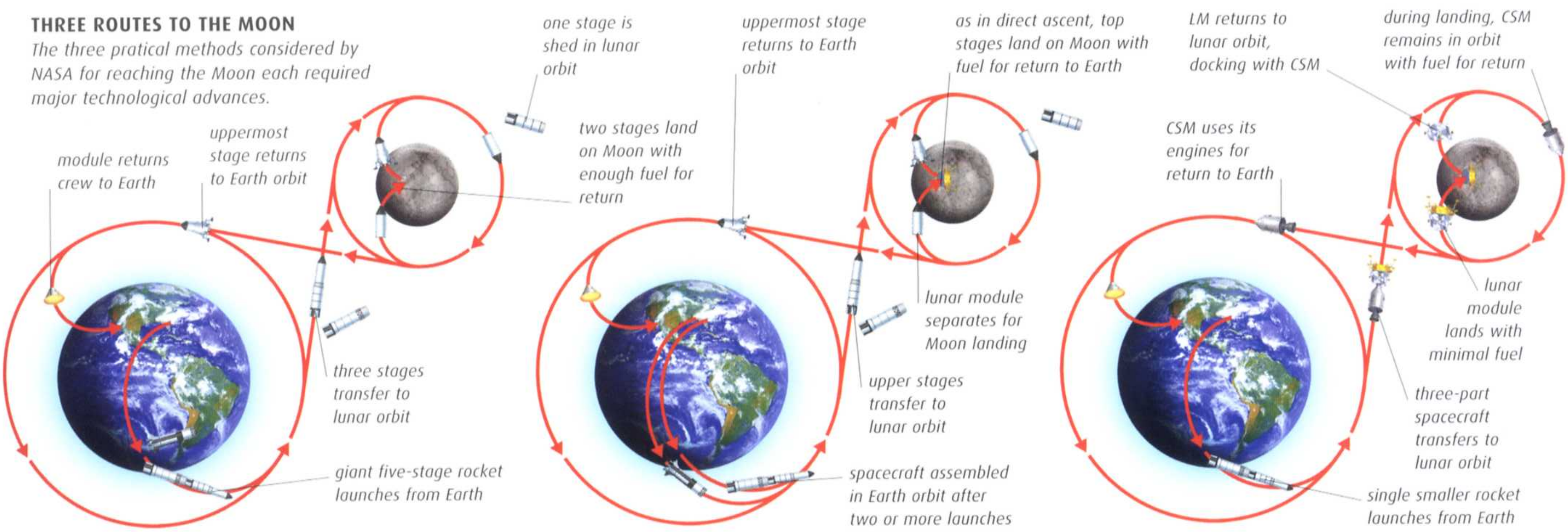
FLYING THE BEDSTEAD
A Moon landing would require precise use of the LM's retro-rockets. To practise descent, astronauts used the ungainly Lunar Landing Research Vehicle, soon nicknamed the Flying Bedstead.

A lunar spaceship

An LOR mission called for a spacecraft with at least two separate elements – a mothership that would remain in orbit around the Moon and a lander that would go down to the surface. To simplify re-entry, NASA ultimately opted to use three distinct elements. The mothership would consist of two sections: a conical Command Module, in which the astronauts would spend most of the journey to and from the Moon; and a cylindrical Service Module that would contain equipment such as the rocket motors needed for manoeuvring in lunar orbit. For almost all of the mission, the two would be united and referred to as the Command and Service Module or CSM. The third element, the Lunar Excursion Module, usually known simply by the initials LM, was a separate spacecraft that would only ever have to fly in a vacuum and so rapidly evolved an ungainly, spider-like shape in which function overruled form.

As usual, NASA operated a contracting process that invited interested companies to bid for the manufacturing work. The contract for the CSM ultimately went to North American Aviation, while the LM was to be built by Grumman Aerospace. By 1966, the initial "Block 1" batch of CSMs was being readied for mounting on rockets and testing on the pad – but the Apollo programme was about to suffer a tragic setback.

THREE ROUTES TO THE MOON
The three pratical methods considered by NASA for reaching the Moon each required major technological advances.



DIRECT ASCENT (DA)
An enormous multi-stage rocket is launched directly towards the Moon. The upper two stages land upright on the lunar surface, still with enough fuel to transport the crew back to Earth.

EARTH ORBIT RENDEZVOUS (EOR)
A lunar spacecraft docks with a huge propellant tank already launched into orbit. The tank has fuel for the journey to the Moon, and the spacecraft touches down with enough fuel for its return.

LUNAR ORBIT RENDEZVOUS (LOR)
A three-stage rocket puts the spacecraft on course for the Moon. Once in lunar orbit, a lunar module descends to the surface while during landing, the CSM remains in orbit with fuel for return.

FIRST LAUNCH
A huge S-I rocket stage is lifted to the launch pad during preparations for the first launch of the Apollo programme in October 1961. Designated SA-1, this was one of a series of early tests of the clustered rocket.

Apollos 1 to 6

Meeting the 1969 deadline for a Moon landing called for a breakneck development and testing programme, but Apollo was almost derailed by tragedy at its birth.

Even though the Saturn launcher had been in development for some time, launching a lunar mission by 1969 would be an enormous challenge. One thing was clear to Dr. George Mueller, NASA's Associate Administrator for Manned Space Flight – the old philosophy of step-by-step rocket testing, altering just one component at a time between tests, would slow things down immeasurably.

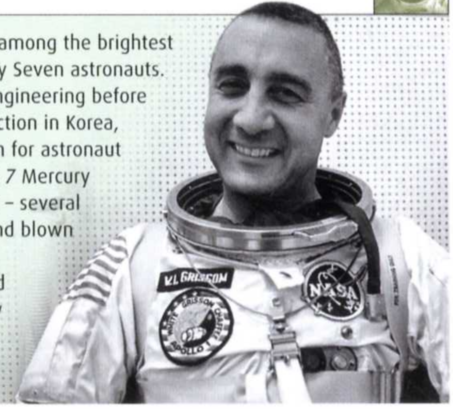
Instead, Mueller opted for the bold approach of all-up testing – launching a complete spacecraft and studying how an entire system worked together. Even if a few repeats of certain missions proved necessary, this would drastically reduce the number of launches required during the testing process. Under the traditional system, it could have taken 20 launches of different Saturn V and Apollo elements to reach a manned lunar landing. Following Mueller's proposals, it might take as few as six Saturn Vs, preceded by a number of Saturn I and IB launches to test boilerplate capsules in Earth orbit.

The first elements of Apollo hardware to be ready for testing were the CSM and the Saturn IB launch vehicle. A manned launch of these components was planned for February 1967, and so it was that on

LOST CREW
In October 1966, the crew of the fated AS-204 (later known as Apollo 1) rehearsed procedures for their splashdown in the Gulf of Mexico. Pictured from left to right on the deck of the NASA's Motor Vessel Retriever *are Ed White, Gus Grissom, and Roger Chaffee.*

BIOGRAPHY

GUS GRISSOM



Virgil "Gus" Grissom (1926–1967) was among the brightest and the best of NASA's original Mercury Seven astronauts. Born in Mitchell, Indiana, he studied engineering before joining the US Air Force. After seeing action in Korea, he was a test pilot prior to his selection for astronaut training. The sinking of the *Liberty Bell 7* Mercury capsule hung like a cloud over Grissom – several people argued that he had panicked and blown the capsule hatch himself. Despite the criticism, Grissom went on to command Gemini 3, and NASA continued to show its confidence in him with his selection for the first Apollo mission.

27 January Gus Grissom, Ed White, and Roger Chaffee were sealed into the CSM on Launch Complex 34 at Kennedy Space Center for a mission simulation. (Shortly after John F. Kennedy's assassination in November 1963, NASA's launch site had been named in his honour and Cape Canaveral itself also bore the Kennedy name until 1973.)

Tragedy strikes

Almost six hours into the test, an electrical spark started a catastrophic fire in the capsule (see over). The flames spread rapidly in the CSM's pure oxygen atmosphere, and difficulties opening the hatch sealed the fate of the crew, who died from smoke inhalation as they struggled to escape.

NASA immediately established a review board that looked into every aspect of the spacecraft design and reached some damning conclusions. Although built by North American Aviation, Apollo's design was ultimately determined by NASA, and several suggestions made by the contractor to improve safety had been overruled. The board recommended a huge number of changes, including a less volatile atmosphere, removal of flammable materials, and more than 1,400 wiring improvements.

Despite the shock of losing three astronauts, there was little talk of abandoning Apollo, and NASA had soon put together a recovery plan. Grissom, White, and Chaffee's AS-204 test mission was retrospectively renamed Apollo 1, and a series of unmanned tests would follow, with Apollo 7 as the next manned launch if all went well.

Unmanned launches

The peculiarities of NASA's mission numbering system meant that the next official Apollo launch was Apollo 4, the first all-up test of a Saturn V. launcher The sight of the mighty rocket thundering into the Florida skies in November 1967 did a great deal to restore American belief in the Apollo programme in the wake of the fire, and the mission went flawlessly, with an empty CSM splashing down just a few kilometres off target after running through a series of orbital manoeuvres.

In January 1968, Apollo 5 saw a Saturn IB launch an unmanned lunar module for testing in Earth orbit, and in April, a second unmanned Saturn V launch, despite some glitches, was considered enough of a success to qualify the rocket for manned flights.

VIEW FROM THE TOP
This stunning view from the top of the Vertical Assembly Building shows the Saturn V rocket stacked in preparation for the Apollo 4 launch. Despite the size of the VAB, the fully stacked Saturn V, on top of its crawler transporter, was too tall to fit in, and the lightning conductor at the rocket's tip had to be erected after it left the building.

27 January 1967
The crew of AS-204 are killed by a fire in their CSM during training.

5 April 1967
The Apollo 204 review board delivers its report to NASA Administrator James Webb.

4 May 1967
NASA renumbers the Apollo missions, designating AS-204 as Apollo 1 at the request of Gus Grissom's widow.

9 November 1967
Apollo 4 sees the successful launch of the first Saturn V rocket.

22 January 1968
The Apollo 5 mission conducts tests of the LM engines in Earth orbit.

4 April 1968
Apollo 6, the second test launch of Saturn V, develops "pogoing" oscillations during launch due to uneven engine burn, then suffers a failure of two second-stage engines. However, with some modifications the Saturn V is eventually approved for crewed spaceflight.

9 October 1968
Modifications to the Apollo spacecraft following the Apollo 1 fire are formally completed.

MOMENT OF TRIUMPH
Wernher von Braun (centre, standing) watches the launch of Apollo 4 at Kennedy Space Center. To his left is George Mueller, head of NASA's manned spaceflight programme. Saturn V was a personal triumph for von Braun, but the Apollo programme effectively derailed the Huntsville team's detailed vision for the conquest of space. In 1970, von Braun was asked to lead NASA's strategic planning, but he left the agency in 1972, working in private industry until his death in 1977.

TECHNOLOGY

THE VEHICLE ASSEMBLY BUILDING

Building the world's largest rocket called for a truly vast hangar, one of the world's largest buildings. Construction work on the Vertical (later Vehicle) Assembly Building or VAB got under way in 1962. The towering building is still one of the world's biggest enclosed spaces – 160m (525ft) high, with four times the volume of the Empire State Building. It contained construction equipment and cranes to assemble the Apollo components, which arrived by barge and aircraft from the various contractors, on top of a huge crawler transporter that then carried the rocket to its pad. Today it is still used for assembling components of the Space Shuttle system.

EXPERIENCE

FIRE ON THE LAUNCH PAD

Apollo 1 ... a tragic start

The fire that devastated the Apollo capsule during the AS-204 ground test claimed the lives of three of America's best and brightest astronauts. And the investigations that followed it laid NASA open to criticism of its management and safety procedures for the first time.

DOOMED CREW
Ed White, Gus Grissom, and Roger Chaffee pose for a photograph with a model of the Command Module in which they would die.

On 27 January 1967, the first Apollo crew, assigned at the time to an orbital test flight designated Apollo 204, boarded their Command and Service Module for a routine test that would, if successful, have paved the way for the first manned Apollo launch a few weeks later. Gus Grissom, Ed White, and Roger Chaffee were to test the CSM's operation in "plugs out" mode – with all external power supplies withdrawn to simulate conditions in space. The test would include a full launch rehearsal.

The spacesuited crew boarded the Command Module at 13:00 local time, but a series of problems with the oxygen supply and faulty communications equipment caused repeated holds in the simulated countdown. By 18:30, the "launch" had reached T-10 minutes, but was again on hold. Then at 18:31 there came a chilling cry over the radio, probably from Roger Chaffee:

"We've got **fire in the cockpit!**"

Seconds later came another cry: "We've got a bad fire – let's get out!". On the television monitors, Ed White was briefly seen struggling to open the hatch, but its design was complex – even in practice, no astronaut had succeeded in getting it open in the suggested 90-second timeframe. Outside, the ground crew also struggled to open the hatch, but they were beaten back by fire as the capsule ruptured. By the time they got the hatch open, the astronauts were dead.

"The catastrophe having occurred at Cape Kennedy on 27 January 1967 is a tragedy not only for the United States of America. The sorrow of American people is shared **by peoples of all countries**. In reality, cosmonauts are somehow representatives of the whole Earth, of the entire mankind **in the boundless Cosmos**, no matter what country has dispatched them."

Soviet Embassy press release, 1 February 1967

ROAD TO DISASTER
After months of ground rehearsals of every aspect of the mission, the Saturn I launch vehicle was stacked on the pad at Launch Complex 34, then the CSM, in its fairing, was winched into place. A launch date was set for 21 February 1967. On 27 January, the astronauts boarded the spacecraft as if preparing for a real launch.

"If we die, do not mourn for us. This is a risky business we're in and **we accept those risks.** The space programme is too valuable to this country to be halted for too long if a disaster should ever happen."

Gus Grissom, interviewed three weeks before the fire

INTERNAL DAMAGE
Highly flammable materials used inside the Command Module fed the fire and produced the toxic fumes that ultimately suffocated the crew.

FIRE TRAP
The CSM had a two-part hatch with an inner section that opened inwards – unlike earlier and later spacecraft, it did not have explosive bolts for an emergency escape. Long before the 90-second nominal escape time, the capsule itself was a blazing inferno.

The investigation that followed the fire was exhaustive and its conclusions about NASA's design specification for the Apollo CSM damning. Reconstruction of events in the capsule suggested that the fire had started in exposed wiring beneath Grissom's couch, spreading rapidly in the pure oxygen atmosphere. The nation went into mourning for their lost astronauts, while the CSM was grounded for extensive redesign. Most significantly, the atmospheric mix onboard was changed, the miles of wires and cables were given improved insulation, and the hatch was redesigned to permit opening in just 10 seconds.

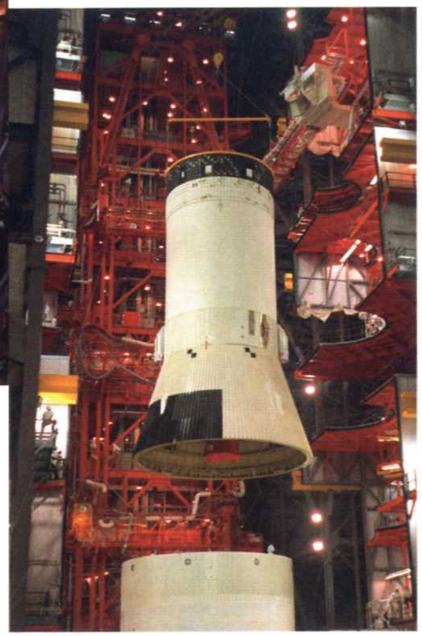
"You know, I suppose you're much more likely to accept the loss of a friend in flight, but **it really hurt to lose them in a ground test.** That was an indictment of ourselves. I mean because we didn't do the right thing somehow."

Neil Armstrong, 2001

MEMORIAL PLAQUE
Launch Complex 34 is now abandoned and dismantled save for the concrete platform where this plaque commemorates the three astronauts who perished.

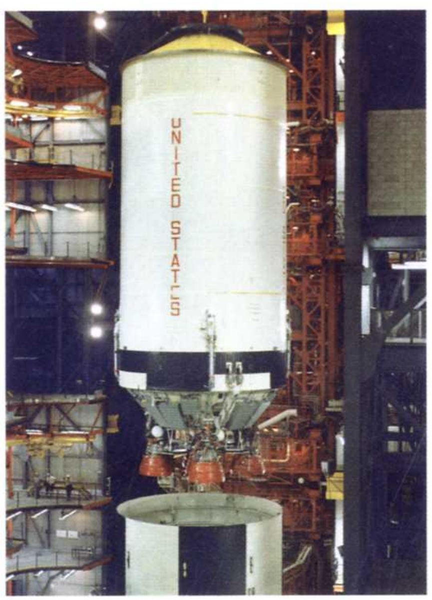
STACKING APOLLO 11

The CSM and LM were stacked at the top of the rocket, with the LM protected by an aerodynamic fairing and stowed beneath the CSM. An escape tower supported a rocket to pull the CM free of the vehicle in an emergency. Once en route to the Moon, the CSM separated from the S-IVB and turned around to dock with the LM and pull it free.



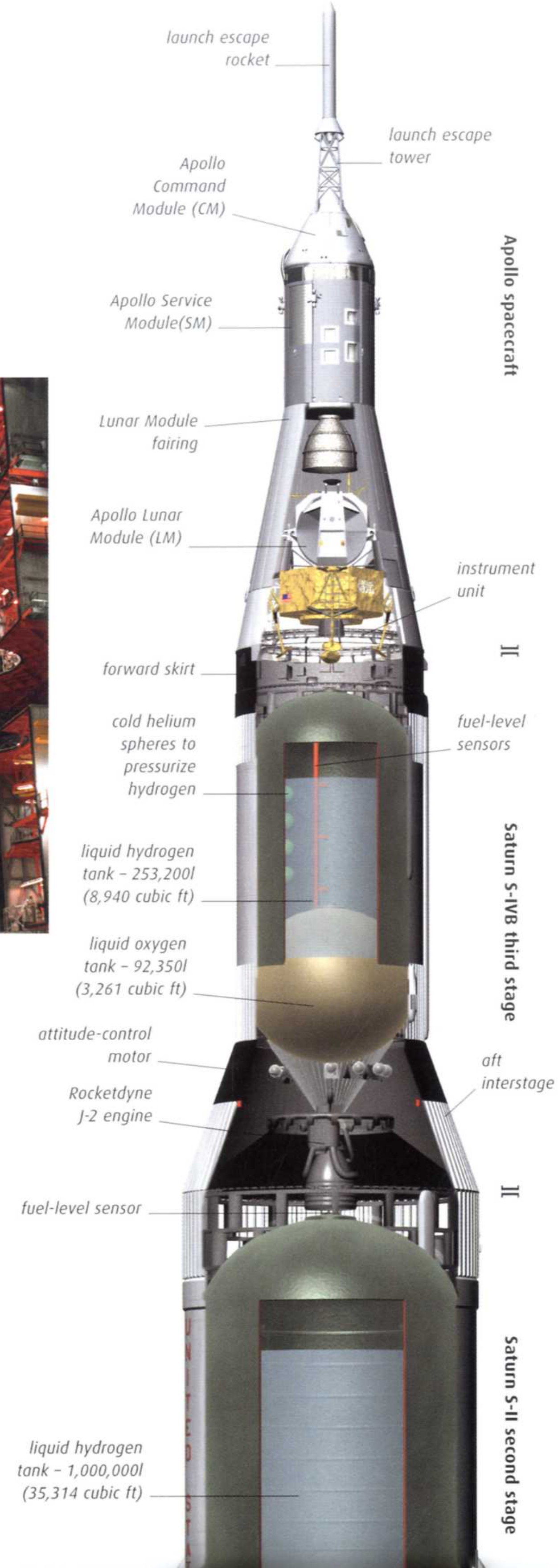
S-IVB THIRD STAGE

The upper stage of the Saturn V performed two main roles – it ignited directly after second-stage separation to reach a low-Earth orbit and then, after several orbits, it reignited to put Apollo on course for the Moon.



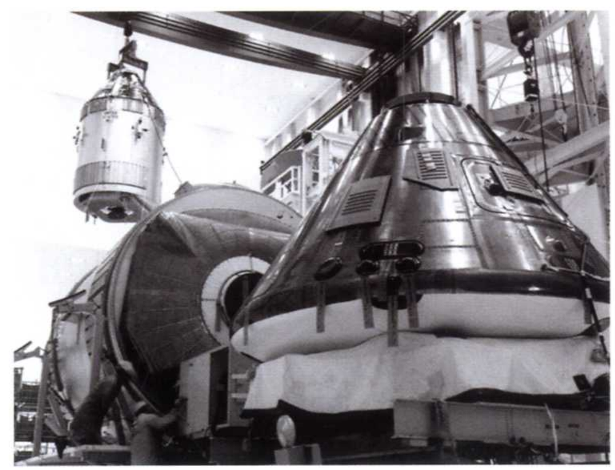
S-II SECOND STAGE

The Saturn V's second stage is lowered towards the S-IC in the Vehicle Assembly Building (VAB). A series of small solid-rocket ullage motors were used to keep up momentum during stage separations. They fired one second after the exhausted first stage jettisoned, pushing the rest of the vehicle forward and away from the first stage and increasing the pressure of fuel in the second stage as its five J-2 engines ignited.



SPECTACULAR DEBUT

The first launch of a Saturn V was on the unmanned Apollo 4 test flight. For an all-up test, it went remarkably well – in 13 launches, the Saturn V never suffered a truly disastrous failure.



MOUNTING THE SPACECRAFT

The elements of the Apollo spacecraft were combined at ground level and enclosed in a protective shroud before being hoisted to the top of the VAB and set on top of their launch vehicle.

Saturn V

Although a lunar mission using Saturn I rockets might have been feasible, the lunar-orbit rendezvous mission that NASA eventually settled on required a much larger and more powerful launch vehicle. This rocket was the Saturn V, the largest rocket ever to fly successfully. Masterminded again by the rocket team at Huntsville's Marshall Space Flight Center, it built on, but did not replicate, the technology of the Saturn I. Fifteen of these giants were ultimately built.

S-1C ASSEMBLY
The first stage, seen here being lifted into place in the VAB prior to the Apollo 8 launch, was powered by five Rocketdyne F-1 engines burning liquid oxygen and kerosene from a pair of huge tanks.

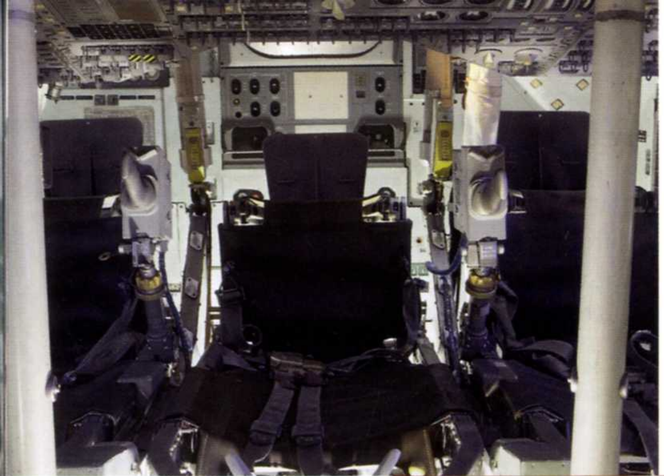
WERNHER'S BABY
Wernher von Braun stands by the massive F-1 engines at the back of a Saturn V launcher (in fact a test vehicle kept at Huntsville). The challenge of reaching the Moon saw him finally abandon the clustered rocket concept of the Saturn I in favour of much larger propellant tanks supplying multiple engines.

SATURN V LAUNCHER
The complete Saturn V stood the height of a building of over 30 storeys. Transported to the pad empty, the weight of its propellants caused it to shrink by 20cm (8in) as it was fuelled.

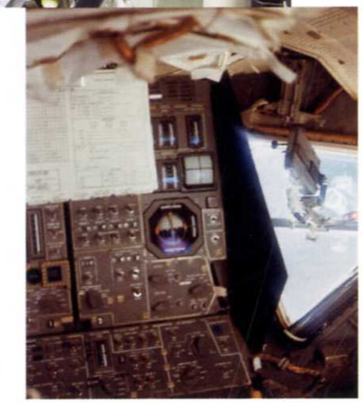
HEIGHT	110.6m (363ft)
MAXIMUM DIAMETER	10.1m (33ft)
WEIGHT AT LAUNCH	3,038,500kg (6,699,000lb)
UNFUELLED WEIGHT	183,395kg (404,317lb)
ENGINES	5 x Rocketdyne F-1 5 + 1 x Rocketdyne J-1
THRUST AT LAUNCH	3,440,344kgf (7,584,582lbf)
MANUFACTURERS	Boeing, North American, Douglas

ON THE MOVE
A prototype S-IC stage is moved into the Propulsion and Vehicle Engineering Laboratory at Marshall Space Flight Center, for testing under stresses and loads similar to those encountered during launch.

DESIGN MOCK-UPS
One of the first tasks at Huntsville was to design engineering models for testing weight characteristics, dimensions, and aerodynamics. This is a full-size mock-up of the S-IC first stage.



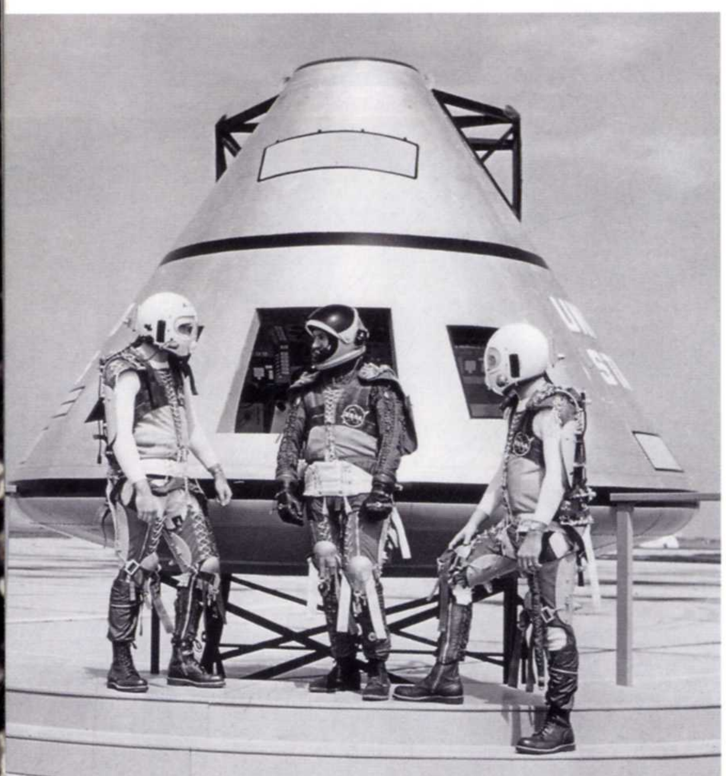
COMMAND MODULE INTERIOR
The three astronauts lay alongside each other on couches during launch and landing. The Commander sat on the left, the Command Module Pilot in the centre, and the Lunar Module Pilot on the right. The open space in the cabin was interrupted by two vertical bars in front of the exit hatch – there to provide structural support in the event of a crash-landing.



CONTROLS AND WINDOWS
The Command Module control panels were directly in front of the astronauts, while five windows formed an arc around the upper half of the CM. Two of these were "rendezvous windows", fitted with a mechanism for use when docking with the LM.

APOLLO COMMAND MODULE
The Command Module was the heart of the spacecraft, where the crew spent the majority of their journey to and from the Moon. It remained in lunar orbit as the LM went down to the surface, and it was the only part of the spacecraft to return to Earth.

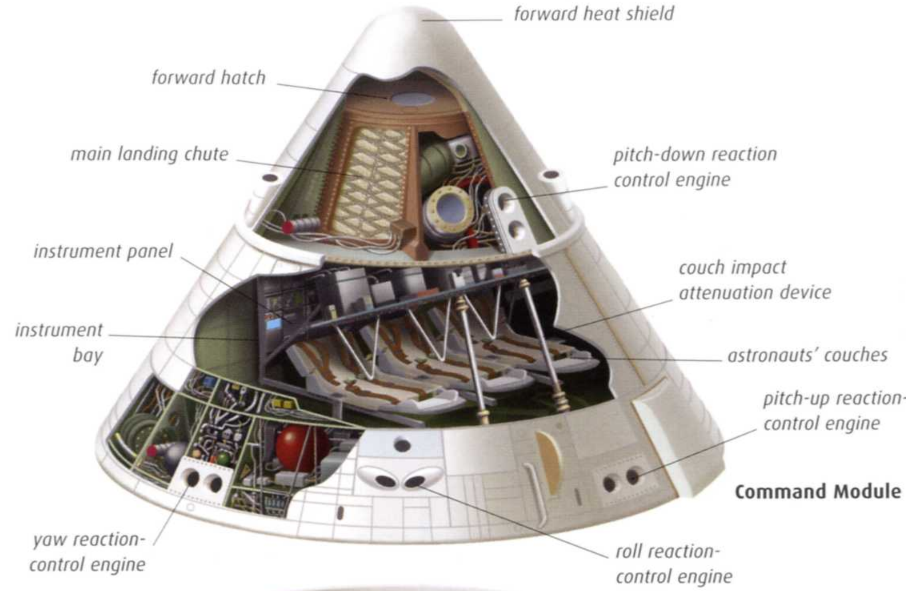
CREW	3
LENGTH	3.47m (11ft 5in)
MAXIMUM DIAMETER	3.92m (12ft 10.5in)
MASS AT LAUNCH	5,947kg (13,090lb)
ENGINES	12 x Reaction Control System thrusters, MMH (hydrazine) and N204 propellant
MANUFACTURER	North American Rockwell



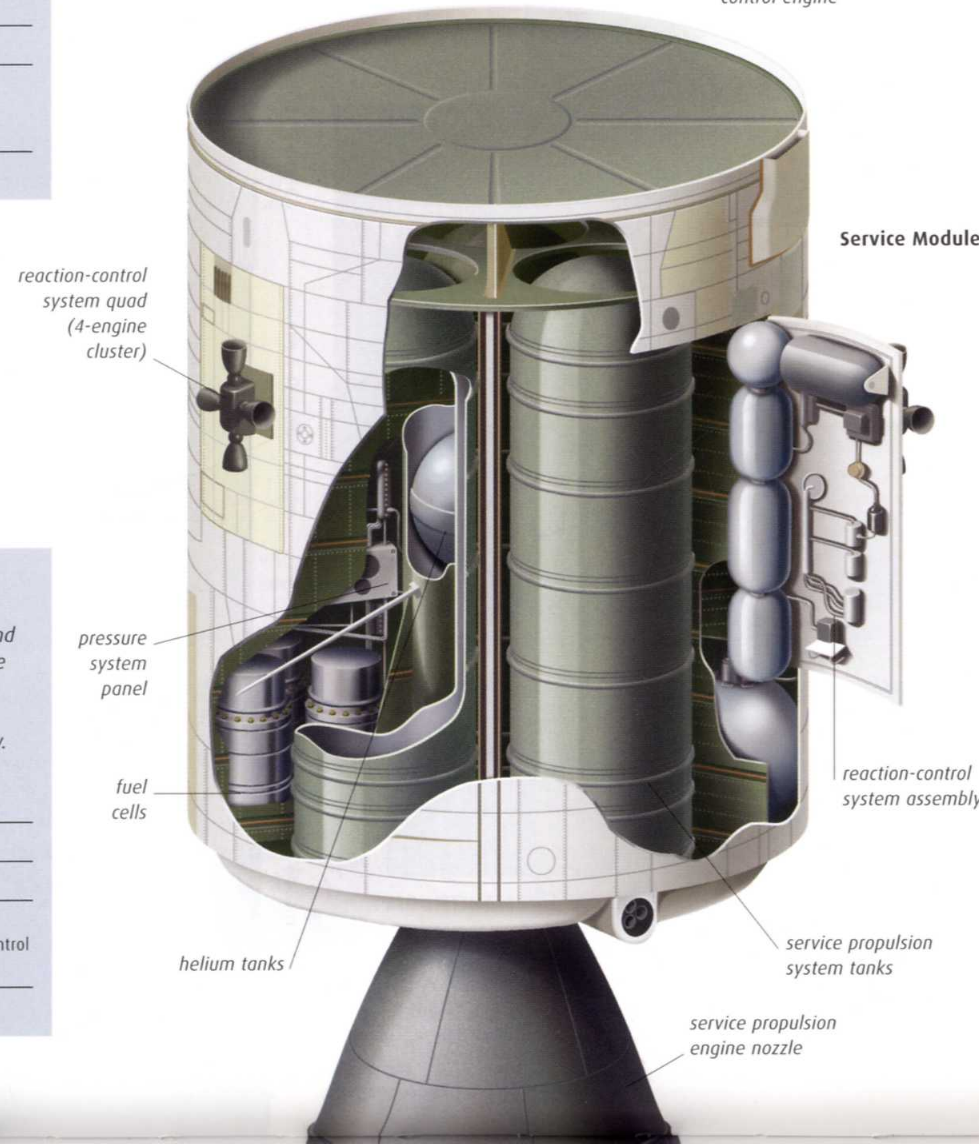
EARLY APOLLO MODULE MOCK-UP
In 1962, a variety of aerospace contractors were invited to submit designs for the Apollo spacecraft elements. This mock-up Command Module was built by Boeing (the "astronauts" are Boeing staff). However, North American Aviation (later North American Rockwell) won the contract.

APOLLO SERVICE MODULE
The Service Module provided life support, power, and other vital needs to the Command Module throughout the flight. It was also the location of the spacecraft's main propulsion engine and numerous smaller thrusters for adjusting the spacecraft's roll, pitch and yaw.

LENGTH	7.56m (24ft 10in)
MAXIMUM DIAMETER	3.92m (12ft 10.5in)
MASS AT LAUNCH	24,582kg (54,074lb)
ENGINES	Service Propulsion System: UDMH/N204; 4 x Reaction Control System quads: MMH/N204
MANUFACTURER	North American Rockwell



Command Module

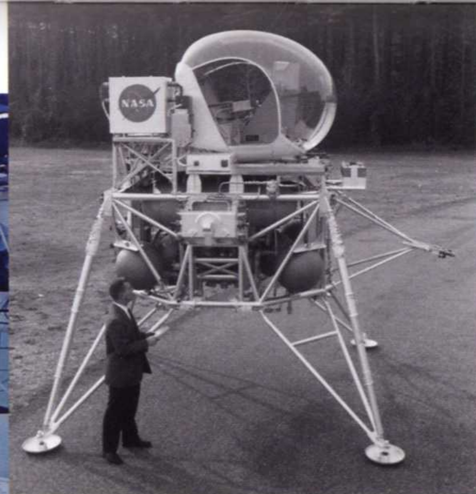


Service Module

Apollo spacecraft

The Apollo spacecraft had three separate elements – the Command Module (CM), Service Module (SM), and Lunar Module (LM), although the Command and Service Modules (CSM) remained linked except during re-entry. Compared to that on Gemini, the docking system was far more sophisticated and allowed access directly from one spacecraft to another for the first time.

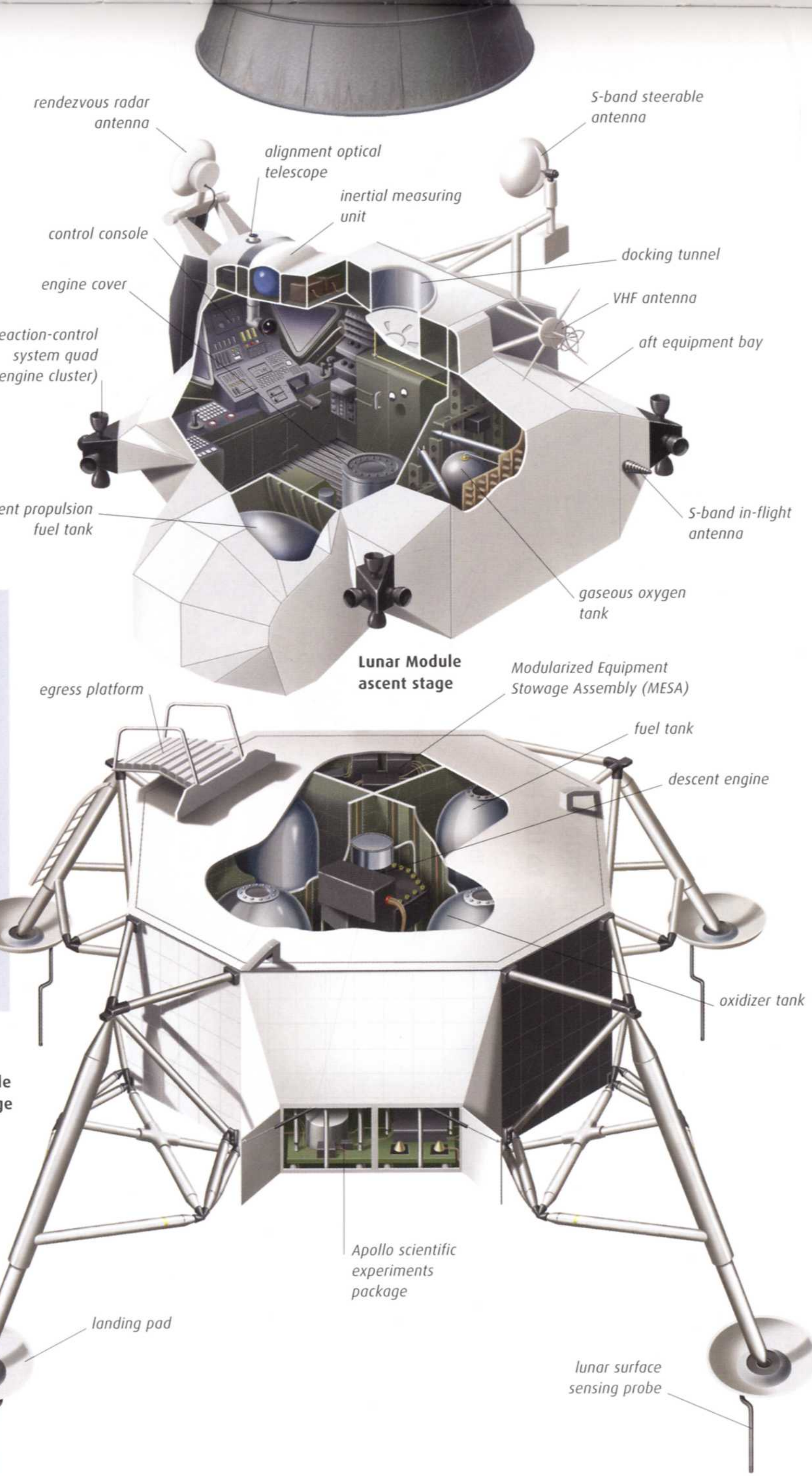
LUNAR MODULE MOCK-UP
Awarded the contract to build the LM, Grumman developed a mock-up, the TM-1, that they used to test the astronauts' practical tasks – such as leaving and returning to the capsule – as well as the ergonomics of the internal equipment layout.



EXPERIMENTAL LUNAR LANDER
As well as the flying bedstead (see p.117), NASA's Langley Research Center developed a number of other training and research vehicles to assess the operation of the LM.

APOLLO LUNAR MODULE
The LM had two elements: a descent stage with spidery legs, a large rocket engine, and much of the equipment that would be left on the Moon; and a polyhedral ascent stage with a small rocket engine and accommodation.

CREW	2
HEIGHT	6.98m (22ft 11in)
WIDTH ACROSS DIAGONAL	9.5m (31ft)
MASS (EARLY MODEL)	15,059kg (33,205lb)
ENGINES	Descent and ascent engines: N204/ Aerozine 50; 4 x RCS quads: N204/UDMH
MANUFACTURER	Grumman Aerospace



1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

10 February 1965
Sergei Korolev's N1 Moon rocket is approved for development.

14 January 1966
Sergei Korolev dies during routine surgery.

11 May 1966
Vasili Mishin is confirmed as the new head of OKB-1.

18 September 1968
The Zond 5 probe loops behind the Moon and returns to Earth safely, landing in the Indian Ocean, in an unmanned test of a lunar orbiter.

30 December 1968
After the successful manned mission of Apollo 8, the Soviet Union abandons the race to put a man on the Moon.

21 February 1969
The first of four test flights of the N1 rocket ends when a fire causes its engines to shut down shortly after launch.

23 November 1972
The last N1 launch ends in an explosion.

17 February 1976
The last elements of the Soviet manned lunar programme are abandoned.

The Soviet challenge

Throughout the 1960s, the Soviet designers suffered a series of setbacks that ultimately brought an end to their hopes of beating the Americans in the race to the Moon.

Despite years of denials and cover-ups, the Soviet Union was racing to keep up with Apollo until almost the last moment. Even before the first cosmonaut had flown, work had begun on the huge N1 rocket, a successor to the R-7 with enough power to match even the mighty Saturn V.

Like the Apollo planners, Soviet designers had to choose between three possible mission profiles (see pp.116–17). At first, Sergei Korolev chose Earth orbit rendezvous – in 1963, he set out a plan that would use three N1 launches and a single launch of the new Soyuz-A vehicle (see over) to build a 200-tonne spacecraft in Earth orbit.

But the Soviet system generated fierce competition between designers, and military rocket designer Vladimir Chelomei, in particular, was becoming increasingly prominent. Chelomei wanted to develop his own superbooster, the UR-700, outclassing even his own UR-500 Proton (see p.210). He believed this would allow an alternative Moon mission – the fuel-squandering direct ascent approach. With Korolev and Valentin Glushko also arguing over engine design and choice of propellant, the entire Soviet Moon programme was soon mired in bureaucracy and politics. It took two vital years for Korolev's lunar project to get the go-ahead, and by then engineering realities had stripped it down to a far less ambitious lunar-orbit rendezvous mission, using a single N1 launch and a spacecraft called the L3, combining a variant of the Soyuz spacecraft, with a new one-man lander called the LK.

Development problems

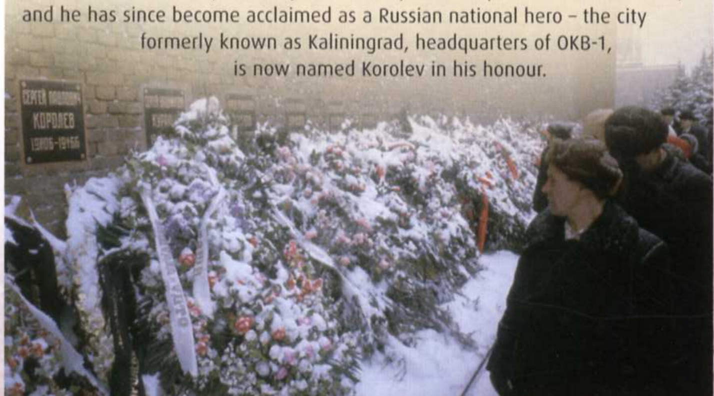
The N1 rocket project lagged behind schedule from the very start, largely thanks to wrangles between the designers and interference from bureaucrats. All this was made inevitable by the sheer scale of the project – it was simply too huge for OKB-1 to handle alone. And then, in January 1966, came the sudden death of Korolev during routine surgery (see panel, below). While

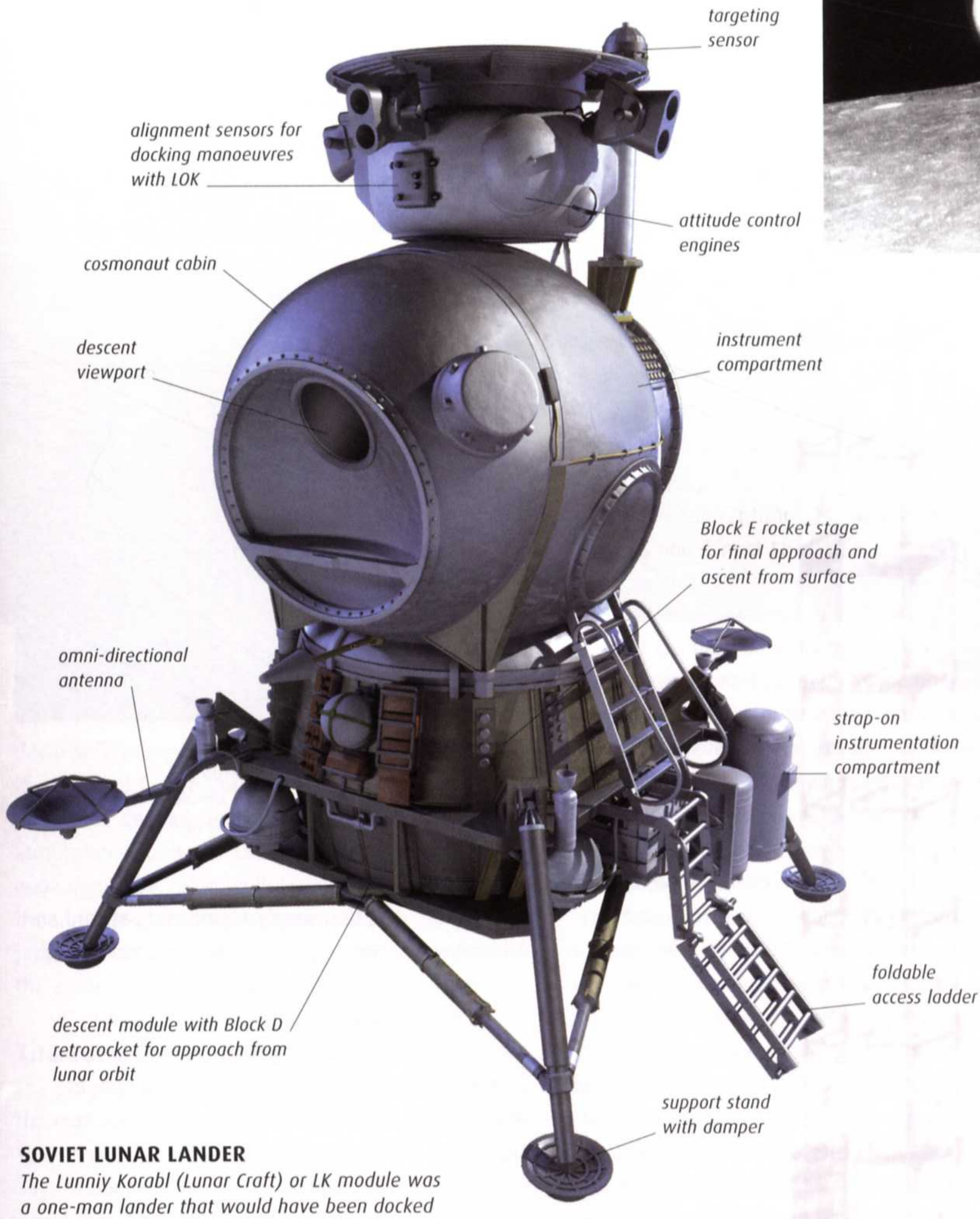
LUNAR GIANT
The enormous N1 rocket, 105m (344ft) tall and 17m (56ft) across, stands ready for a launch on its specially built pad at Tyuratam.

HISTORY FOCUS

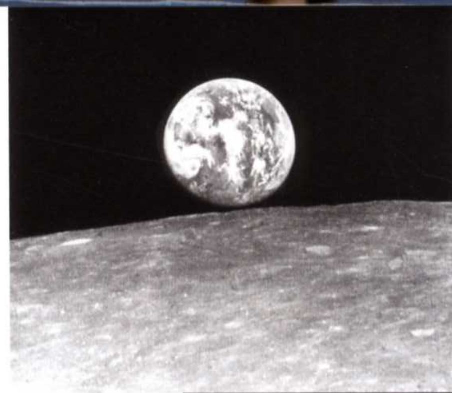
THE DEATH OF THE CHIEF DESIGNER

Sergei Korolev died on 14 January 1966, after complications that developed during routine colon surgery. It was only after his death that the Soviet authorities finally allowed his identity to become widely known. Korolev's funeral left the Soviet space programme rudderless. His larger-than-life, driven personality, combined with a pragmatic recognition of the need to play the Soviet political game, meant that he was recognized as leader, sometimes reluctantly, even among the other chief designers. His pivotal role in the Soviet conquest of space has only become public since the 1970s, and he has since become acclaimed as a Russian national hero – the city formerly known as Kaliningrad, headquarters of OKB-1, is now named Korolev in his honour.

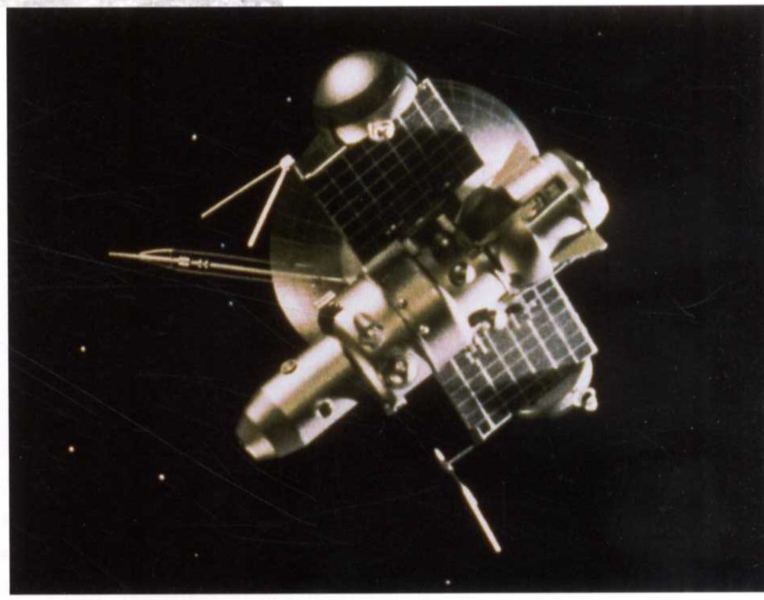




SOVIET LUNAR LANDER
The Lunniy Korabl (Lunar Craft) or LK module was a one-man lander that would have been docked with a Soyuz-derived LOK spacecraft for the trip to the Moon. Three successful unmanned tests in Earth orbit were listed as Cosmos satellites.



UNMANNED MOON SHOTS
The Luna programme continued throughout the 1960s. Key achievements included the first craft in lunar orbit and the sending back of the first pictures from the surface, in February 1966.



ZOND MISSIONS
One minor success of the Soviet lunar programme was the launch of the Zond probes – unmanned Soyuz spacecraft without an orbital module, designed to loop around the Moon and return to Earth in rehearsals for a similar manned flight.

the Soviets had many other capable designers, the loss of their leading light left the programme temporarily rudderless. In the aftermath, OKB-1 was restructured and there was a four-month delay before Vasili Mishin, Korolev's deputy, was appointed as his successor. All this time, the Soviets were lagging further behind Apollo, but the situation was so confused that, as late as February 1967, the Soviet government could talk of a landing in late 1968.

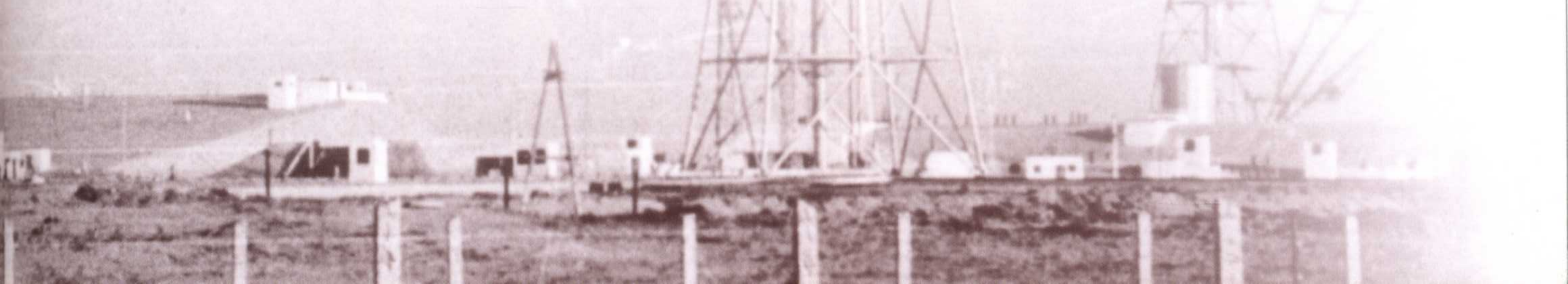
By the time that never-realistic deadline rolled around, the truth was unavoidable – the N1 and its LK lunar lander still languished in development, while Saturn V rockets shook the ground at Cape Canaveral and a manned American spacecraft orbited the Moon. Nikolai Kamanin, in particular, blamed the whole fiasco on infighting and a mistaken design philosophy that treated the cosmonauts as passengers and therefore developed overcomplex, fully automated spacecraft before worrying about clearing them for manned flight.

The big lie

On 30 December 1968, Soviet space leaders met to discuss their response to Apollo 8 and their impending defeat. Mstislav Keldysh proposed a novel solution – using Chelomei's Proton rocket to launch a robotic mission that would collect and return samples of lunar rock, hopefully ahead of a manned American landing. State-controlled media, meanwhile, would make it clear that the manned lunar programme had never existed – the Soviet Union would not dream of risking the lives of its heroic cosmonauts for a political stunt. Fortunately, the growing success of Soyuz provided them with an ideal cover story.

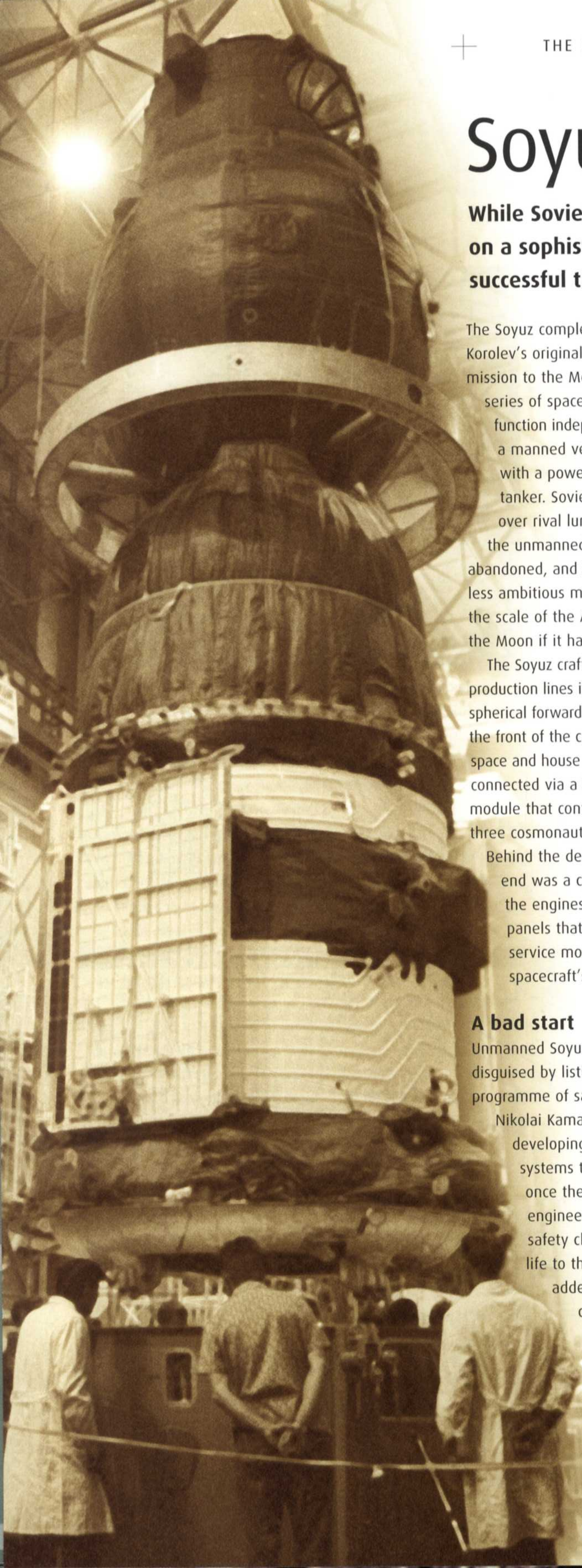
And so, in July 1969, the Luna 15 probe raced towards the Moon ahead of Apollo 11 – only to add to Soviet embarrassment by crashing during its final descent onto the Sea of Crises. In the following years, the Soviets would have greater success with unmanned probes (see p.258), but the truth would not emerge until after the country's collapse in 1991.

And even after Apollo 11, Soviet lunar plans did not die swiftly. The L3 spacecraft was abandoned in favour of development of the larger L3M, which might have landed of the Moon in the mid-1970s, and paved the way for a Soviet Moonbase. The N1 project spluttered on until 1974, when it was finally cancelled in the aftermath of four launch failures.



Soyuz takes shape

While Soviet plans for the Moon stalled in the mid-1960s, work continued on a sophisticated new spacecraft. The Soyuz design ultimately proved so successful that it is still used, in modified form, to this day.



The Soyuz complex was the centrepiece of Sergei Korolev's original plan for an Earth-orbit rendezvous mission to the Moon. The Chief Designer envisaged a series of spacecraft with different roles that could function independently or together. Soyuz A was a manned vehicle, Soyuz B an unmanned craft with a powerful rocket motor, and Soyuz V a fuel tanker. Soviet bureaucracy and the confusion over rival lunar missions ultimately forced the unmanned engine block and tankers to be abandoned, and Soyuz A was redefined as a smaller, less ambitious modular spacecraft (though still on the scale of the Apollo CSM and capable of going to the Moon if it had been given the chance).

The Soyuz craft that began to roll off Soviet production lines in 1966 had three distinct parts. A spherical forward section, the orbital module, sat at the front of the capsule and would provide working space and house equipment needed in orbit. This connected via a hatch to a bell-shaped descent module that contained couches to accommodate three cosmonauts during launch and return to Earth. Behind the descent module's heat-shielded broad end was a cylindrical service module, containing the engines and other spacecraft systems. Solar panels that extended to either side of the service module could be used to recharge the spacecraft's batteries while in orbit.

A bad start

Unmanned Soyuz test launches were mostly disguised by listing them under the catch-all Cosmos programme of satellites. Although cosmonaut chief Nikolai Kamanin criticized the time wasted in developing fully automated spacecraft with systems that would become redundant once they had a crew onboard, most of the engineers felt this allowed for extensive safety checks before trusting a cosmonaut's life to the vehicle. In this case, it also added versatility – an unmanned Soyuz controlled from the ground might

UNDER CONSTRUCTION
Engineers at OKB-1 inspect Soyuz 9 during assembly. The orbital module is at the top, then the descent module, with the service module at the base.

KOMAROV IN TRAINING
Cosmonaut Vladimir Komarov, veteran of the Voskhod 1 mission, works at a simulator console during preparations for his ill-fated flight aboard Soyuz 1.

one day be used to resupply cosmonauts aboard an orbiting space station (an idea that reached fruition with the Progress supply ferry – see p.210).

Cosmonaut Vladimir Komarov was chosen to fly the first manned mission, Soyuz 1. The launch, on 23 April 1967, went well but problems began to develop soon afterwards. The initial plan was for Soyuz 2 to launch the next day with a three-man crew. The vehicles would rendezvous in space, and two cosmonauts would spacewalk to Soyuz 1, returning to Earth with Komarov. But a problem unfolding the solar panels left Soyuz 1 critically short on power and incapable of playing its part in

BIOGRAPHY

VASILI MISHIN

Vasili Pavlovich Mishin (1917–2001) was among the Soviet scientists sent to Germany in 1945, where he first met Sergei Korolev. On his return to the Soviet Union, Mishin became Korolev's deputy at OKB-1 and helped the bureau and the Soviet Union to take the lead in the Space Race. Staff lobbied for his promotion to Chief Designer after Korolev's death, and Mishin oversaw the early Soyuz and Salyut programmes. However, he was ousted from the post in favour of Valentin Glushko after the failure of the N1 Moon rocket.

ZARYA CALLING
Controllers and visiting family members at Baikonur's Spaceflight Control Centre (often known by its callsign Zarya, meaning "Sunrise") take advantage of a brief communication window during the Soyuz 9 mission.

EATING BREAKFAST
Andrian Nikolayev samples breakfast aboard Soyuz 9. When the cosmonauts landed after 18 days, they were weakened by their experience, though they made a good recovery. Later flights showed that longer stays would allow the body to adapt better and that if they exercised properly the cosmonauts would actually return in better shape.

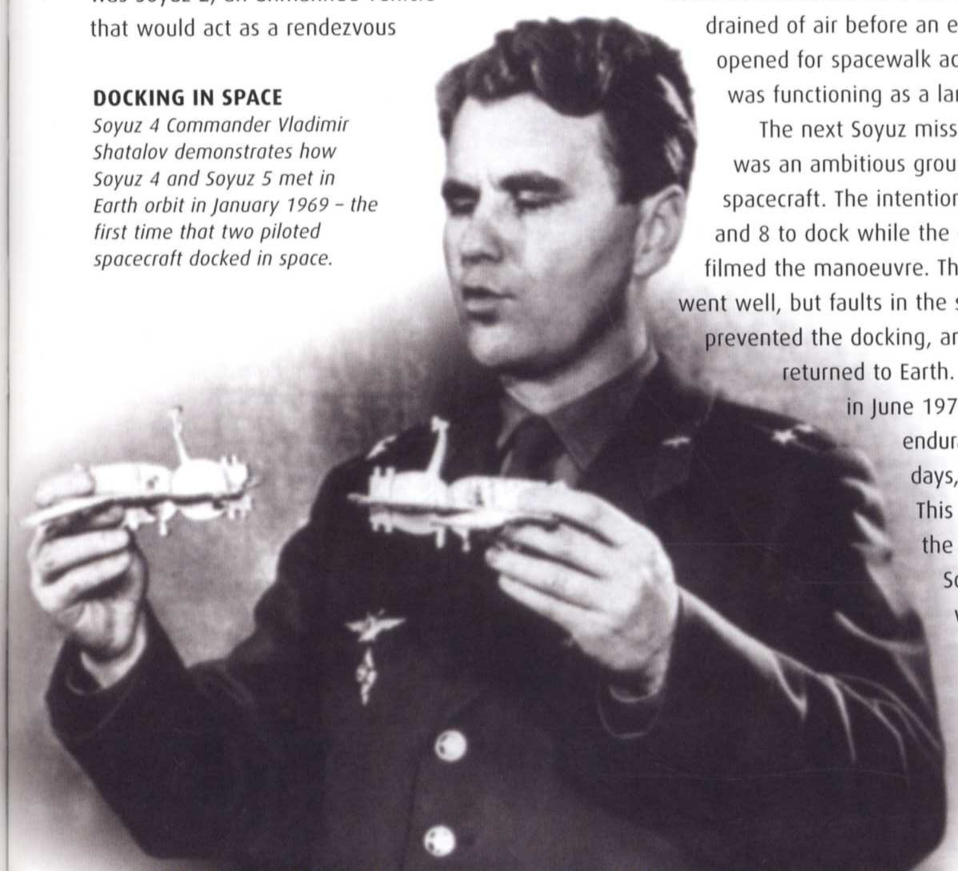
the manoeuvre. The second launch was scrubbed as mission controllers concentrated on getting Komarov down safely. Soyuz 1 was proving difficult to stabilize in orbit, and two re-entry attempts were aborted before the descent module finally plunged into the atmosphere during its 18th orbit. The return to Earth appeared to be going well, but disaster struck when the module's braking parachute failed to deploy properly. Komarov died instantly as his capsule hit the ground near Orsk in the Ural mountains.

The road to recovery

The programme was immediately suspended for a thorough safety overhaul, adding to the woes of the Soviet lunar effort. It was to be 18 months before a Soyuz took to the skies again, in October 1968. This was Soyuz 2, an unmanned vehicle that would act as a rendezvous target for Georgi Beregovoi, launched aboard Soyuz 3 the next day. After achieving the mission's limited aim of testing the spacecraft's manoeuvring and rendezvous systems, Beregovoi returned to Earth safely four days after launch, and the Soyuz programme began to inspire some confidence.

The following January, a joint flight of Soyuz 4 and 5 finally achieved the aims of the original Soyuz 1 mission. The two spacecraft rendezvoused and docked in orbit, and Yevgeny Khrunov and Alexei Yeliseyev spacewalked from Soyuz 5 to Soyuz 4, joining their comrade Vladimir Shatalov for the return to Earth, while Boris Volynov came home alone aboard Soyuz 5. The transfer was another indication of the spacecraft's versatility – the orbital module could be sealed off from the descent module and drained of air before an external hatch was opened for spacewalk access – effectively, it was functioning as a large airlock.

The next Soyuz mission, in October 1969, was an ambitious group flight of three spacecraft. The intention was for Soyuz 7 and 8 to dock while the crew of Soyuz 6 filmed the manoeuvre. The rendezvous in orbit went well, but faults in the spacecraft electronics prevented the docking, and the three crews returned to Earth. Soyuz 9, launched in June 1970, set a new space endurance record, of 18 days, for its two-man crew. This was intended to be the last independent Soyuz mission – flights would now rendezvous with the new Salyut space stations.



DOCKING IN SPACE
Soyuz 4 Commander Vladimir Shatalov demonstrates how Soyuz 4 and Soyuz 5 met in Earth orbit in January 1969 – the first time that two piloted spacecraft docked in space.

18 October 1965
The Soyuz programme is reoriented to the development of a smaller Earth-orbiting spacecraft.

23 April 1968
Soyuz 1 runs into trouble after launch and plans to rendezvous with another Soyuz are cancelled.

23 April 1968
Vladimir Komarov is killed when Soyuz 1's parachute fails after re-entry.

26 October 1968
Georgi Beregovoi is launched aboard Soyuz 3 on a mission to rendezvous with the unmanned Soyuz 2.

16 January 1969
Soyuz 4 and 5 rendezvous and dock in orbit, transferring crew between spacecraft during a spacewalk.

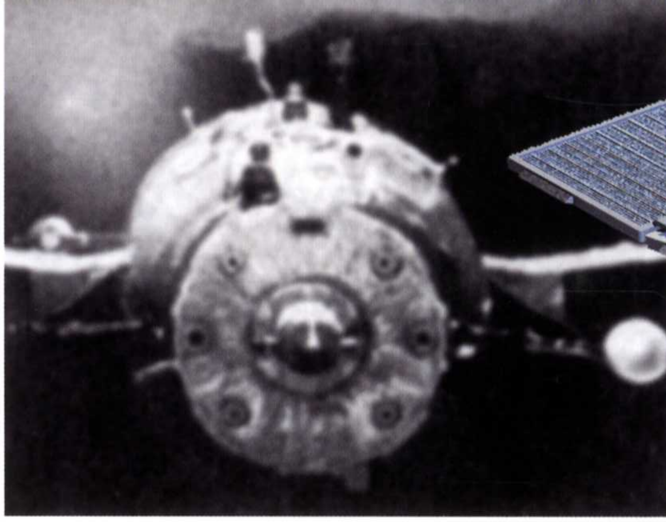
14 October 1969
Soyuz 6, 7, and 8 conduct the first rendezvous between three spacecraft in orbit, but Soyuz 7 and 8 fail to dock.

1 June 1970
Soyuz 9 is launched on an 18-day endurance mission for its crew.

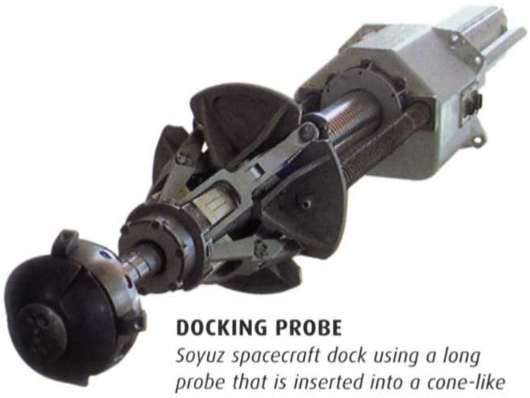
TECHNOLOGY

THE SOYUZ ROCKET

The Soyuz spacecraft was considerably heavier than previous Soviet manned spacecraft. In order to lift it to orbit, Korolev's bureau developed a modified version of the R-7, which by the mid-1960s was an established, trustworthy launch vehicle. Like the Vostok rocket, the Soyuz has two main stages with four boosters around the lower stage – the main difference is that in this case the upper stage was provided with a more powerful engine. Despite its age, the launcher's reliability has ensured that it remains in service today.

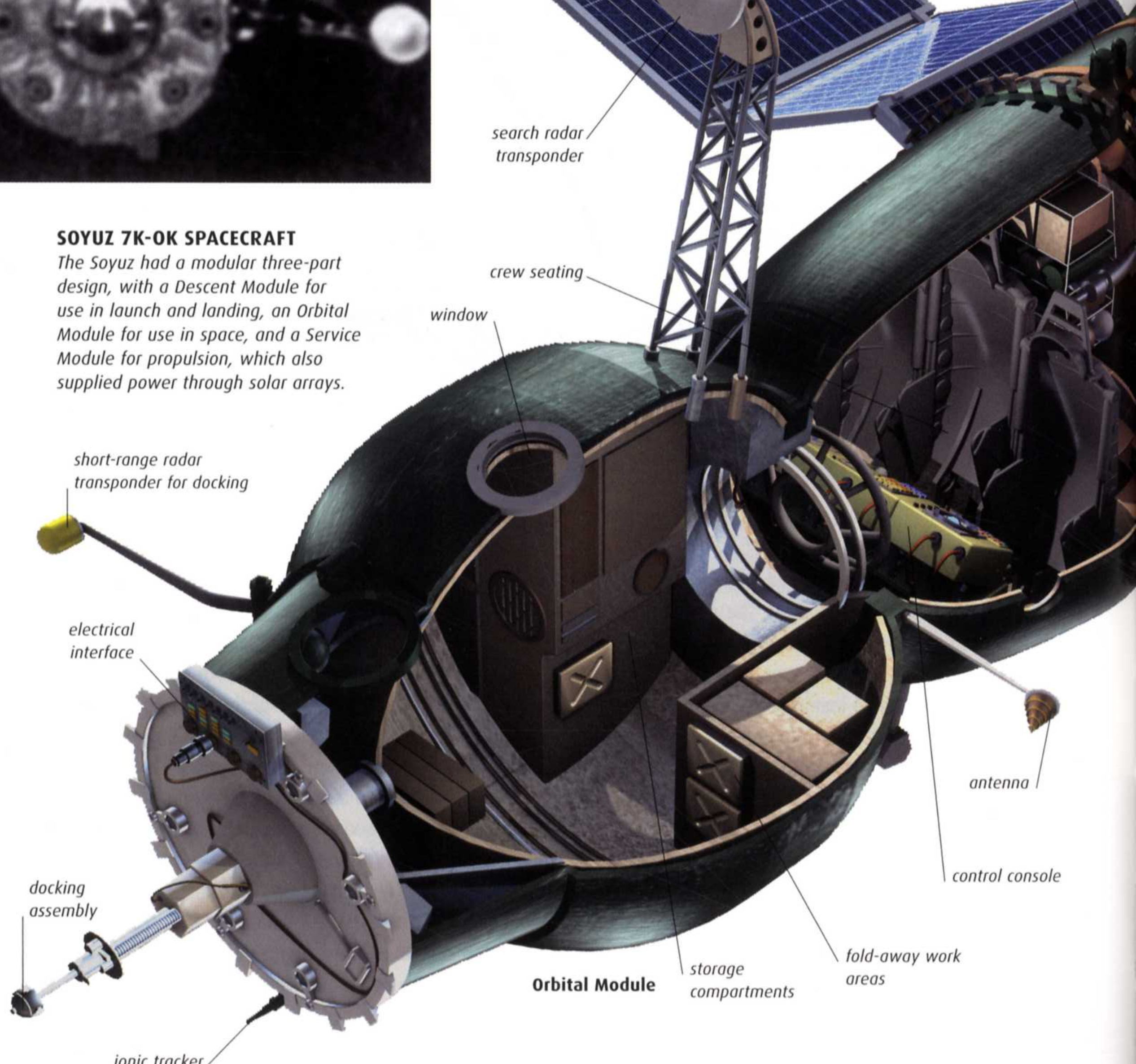


DOCKING IN SPACE
In January 1969, Soyuz 5 loomed large in the porthole of Vladimir Shatalov's Soyuz 4 spacecraft, moments before the first docking of two manned vehicles in space. Shatalov picked up two passengers from Soyuz 5, but they had to spacewalk between the orbital modules in order to reach him.



DOCKING PROBE
Soyuz spacecraft dock using a long probe that is inserted into a cone-like target mechanism on the other vehicle. The probe is then retracted, triggering latches that pull the spacecraft back in to form an airtight seal.

SOYUZ 7K-OK SPACECRAFT
The Soyuz had a modular three-part design, with a Descent Module for use in launch and landing, an Orbital Module for use in space, and a Service Module for propulsion, which also supplied power through solar arrays.



LENGTH	7.95m (26ft 1in)
MAXIMUM DIAMETER	2.72m (8ft 11in)
SOLAR ARRAY SPAN	9.9m (32ft 1in)
WEIGHT AT LAUNCH	6,560kg (14,460lb)
WEIGHT AT LANDING	2,810kg (6,190lb)
CREW	3
ENGINE	1 x main engine: nitric acid/ hydrazine; 36 x RCS thrusters: hydrogen peroxide
MANUFACTURER	Korolev (OKB-1)

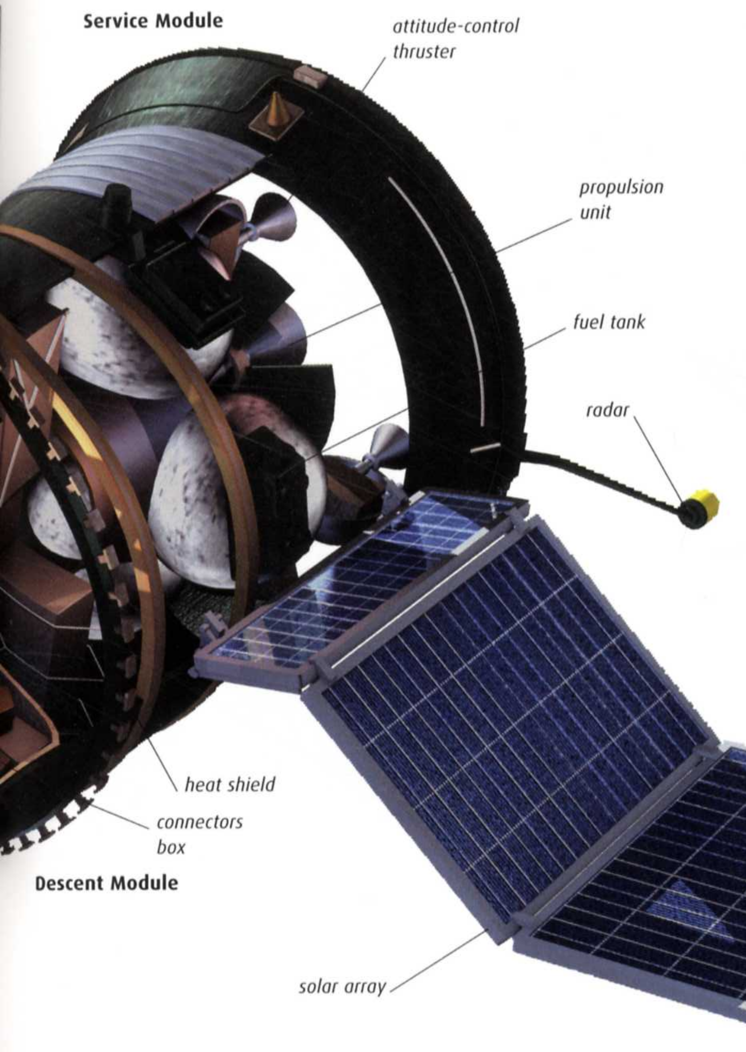
TECHNOLOGY

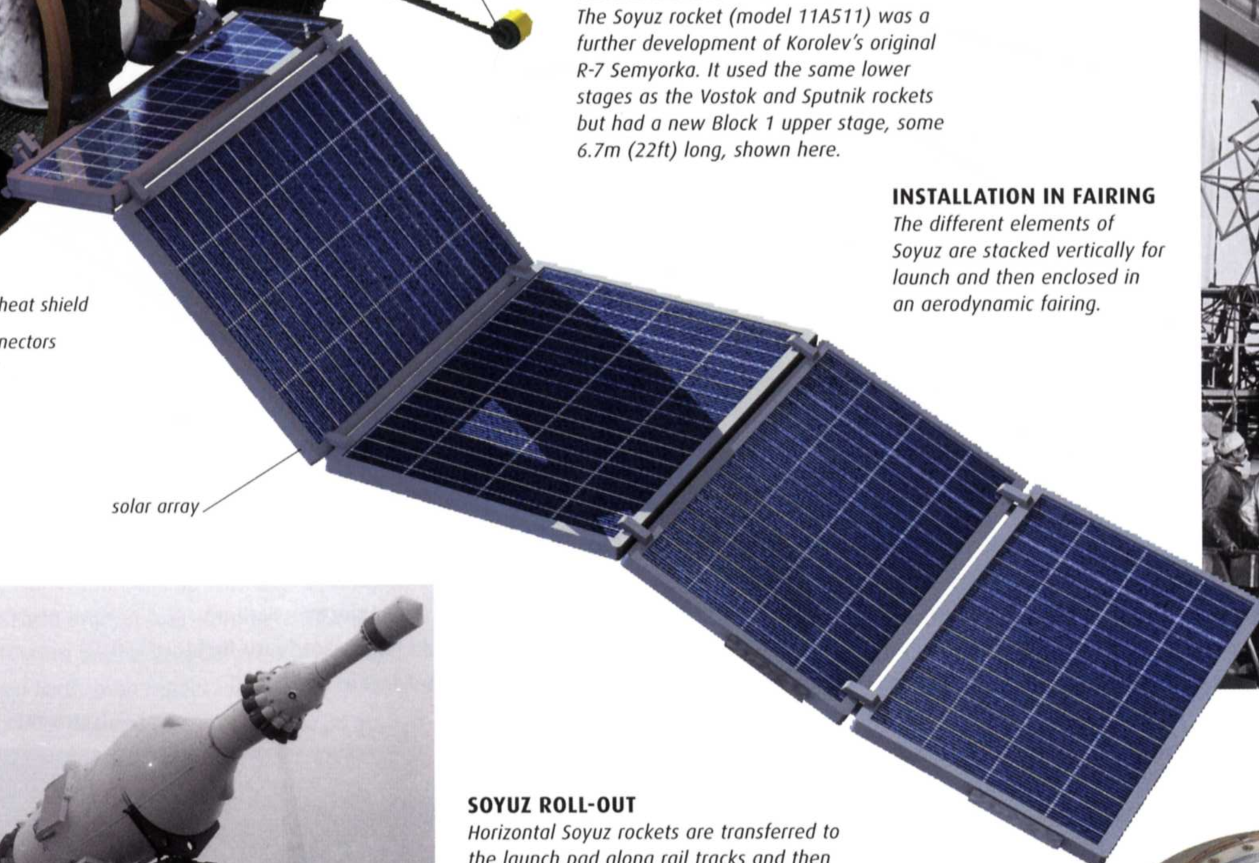
RUSSIA'S MULTI-PURPOSE SPACECRAFT

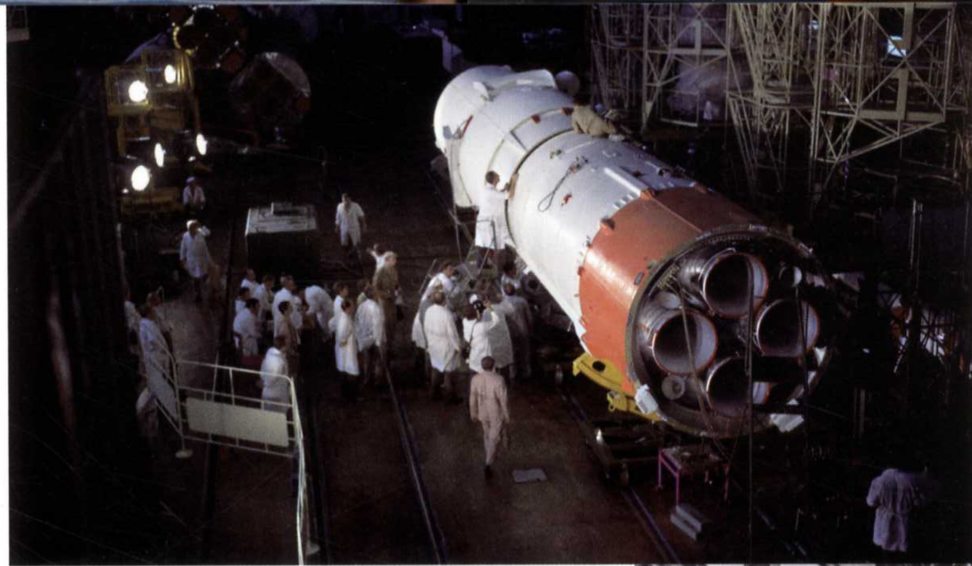
Soyuz spacecraft

Sergei Korolev's lasting legacy to Russian spaceflight, the Soyuz entered service in 1967 and is still operating, in upgraded form, 40 years later. The multipurpose vehicle was the first Soviet spacecraft capable of docking with other craft in orbit, but the first version, model 7K-OK, did not allow the crew to move between craft. This ability arrived with the 7K-OKS (Soyuz 11), but after the loss of that mission's crew, the spacecraft was given an extensive redesign, producing the two-man 7K-T, which operated through the 1970s.

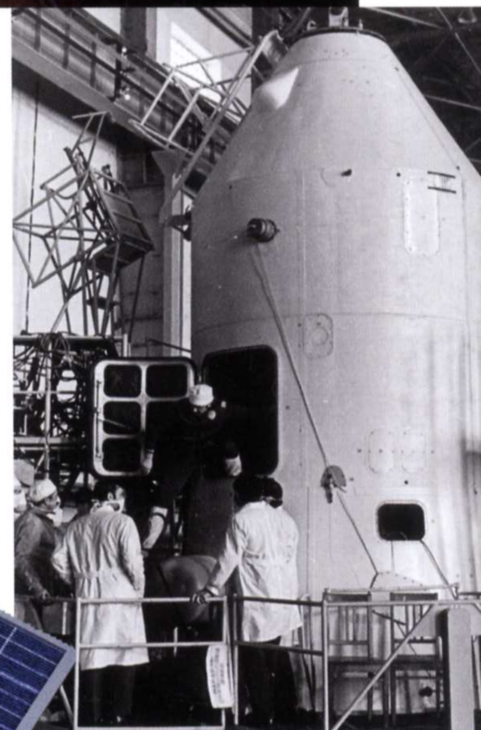
FLIGHT CONTROLS
Soyuz was the first Soviet spacecraft with its own propulsion, enabling it to change its orbit and make other manoeuvres in space. An increasingly sophisticated Igla rendezvous system used radio signals to guide the Soyuz towards a docking target. The more recent Kurs system allows the entire process to take place automatically and is used on Progress, the Soyuz-derived unmanned ferry *(see p.210).*







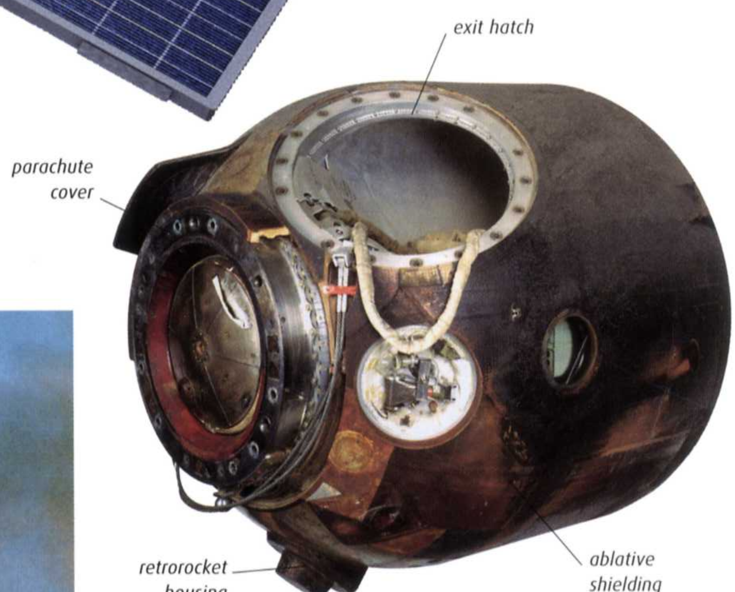
NEW LAUNCHER
The Soyuz rocket (model 11A511) was a further development of Korolev's original R-7 Semyorka. It used the same lower stages as the Vostok and Sputnik rockets but had a new Block 1 upper stage, some 6.7m (22ft) long, shown here.



INSTALLATION IN FAIRING
The different elements of Soyuz are stacked vertically for launch and then enclosed in an aerodynamic fairing.

SOYUZ ROLL-OUT
Horizontal Soyuz rockets are transferred to the launch pad along rail tracks and then pushed upright by a hydraulic ram on the transporter. Retractable gantries around the pad then swing across to lock the launch vehicle into place.

LAUNCH OF SOYUZ 3
The second manned flight of the Soyuz spacecraft blasts off from Baikonur Cosmodrome in October 1968, on its way to attempt the first Soviet rendezvous and docking in space.



RETURN TO EARTH
The Descent Module is the only section that returns to Earth. As it approaches the ground on its parachute, retrorockets fire at the last moment to ensure a soft landing.

1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

Apollos 7 and 8

By late 1968, NASA officials were ready to let the spacecraft fly at last. The initial manned missions tested the Apollo Command Module in Earth orbit, and then took it on the journey to the Moon and back.

18 May 1967
The crew for Apollo 7 is officially named.

7 August 1968
George Low, Apollo Program Manager, suggests sending Apollo 8 around the Moon.

17 August 1968
NASA Administrator James Webb agrees to the new Apollo 8 mission, pending a successful flight for Apollo 7.

11 October 1968
Apollo 7 is launched into Earth orbit on an 11-day mission.

22 October 1968
After a fractious, though ultimately successful, mission, the Apollo 7 Command Module splashes down.

21 December 1968
The first manned Saturn V rocket launches Apollo 8 on its historic mission to the Moon.

24 December 1968
A precise engine burn puts Apollo 8 in lunar orbit.

27 December 1968
The Apollo 8 astronauts splash down safely.

In the aftermath of Apollo 1, Wally Schirra, Donn Eisele, and Walter Cunningham moved up to become the prime crew for the next manned mission. Despite the fact that the lunar module was not ready for flight, the crew included a Lunar Module Pilot (Cunningham), and so Apollo 7 became America's first three-man space mission. Its main aims were to test the Command and Service modules within a safe distance of Earth, over a period of 11 days – more than enough time to make it to the Moon and back.

War in space

Apollo 7 blasted into orbit on a Saturn IB launcher on 11 October 1968. It was to be a stressful mission for everyone involved – both in orbit and at mission control. Although the spacecraft itself worked without any major problems, the crew suffered during their orbital confinement. The stress of giving Apollo a thorough "shakedown" was bad enough, but much of the mission was to be broadcast on live television. Schirra came down with a cold soon after launch, and as it spread to his crewmates, all three became irritable. They insisted that they should be allowed to get on with the real work of the mission without worrying about TV cameras, so the first live broadcast from space was postponed until later in the flight.

This was only one of several occasions when tensions surfaced between the crew and Mission Control – Schirra called some of the tests he had to carry out "idiotic", while Chris Kraft labelled him "paranoid". Despite all this, the crew completed their major goals, and splashed down on time and on target. In the aftermath, Deke Slayton called the incident "the first space war", and it was no coincidence that the Apollo 7 crew were not selected for further missions.

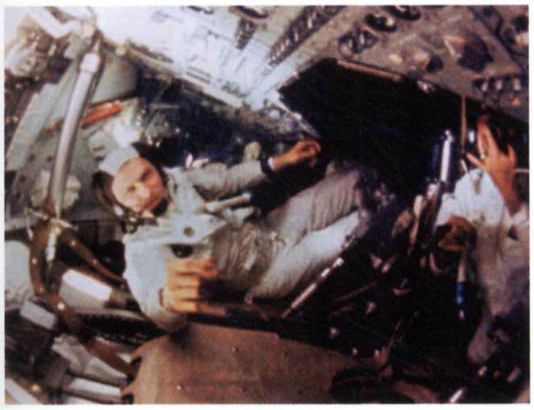
From the Earth to the Moon

Despite the recriminations, Apollo 7 had been a resounding success. According to the original plan, the next step should have been a test of the Lunar Module in Earth orbit, but events had already conspired to give Apollo 8 a new objective. For one thing, the Lunar Module would not be ready for flight until early 1969. With a further test in lunar orbit

TESTING, TESTING
During their mission, the Apollo 7 astronauts practised traditional navigation by taking sightings from bright stars through the CSM's small but serviceable windows.

WRITING IN SPACE
Walter Cunningham takes notes aboard Apollo 7. Contrary to popular myth, NASA did not spend millions on a "space pen" – the pen was developed by a company that managed to get them adopted by NASA.

DOCKING PRACTISE
Once the CSM was free of its S-IVB upper stage (right), the crew practised the docking manoeuvres that would be needed to link up with the Apollo LM. The white disk just off centre (left) marked the docking target.



EN ROUTE TO THE MOON
After the cramped conditions of Mercury and Gemini, which saw the astronauts essentially confined to their seats, the Apollo CSM was relatively spacious. Here, Frank Borman enjoys floating free in zero gravity.

still needed ahead of a first landing attempt, and the ever-present risk of a problem that might require the insertion of a repeat flight into the schedule, Apollo would run very close to its deadline with three such crucial missions in one year.

Then there were the Soviets: no one knew the state of the rival lunar programme, but everyone assumed that it was more advanced than the reality. The unmanned Zond 5 had circled the Moon and returned to Earth weeks before Apollo 7's launch. Given that the CIA was also reporting a Soyuz spacecraft would soon link up with a group of fuel tankers in Earth orbit, it was starting to look like the Soviets were on the verge of a lunar mission involving an Earth-orbit rendezvous (EOR).

And so NASA decided that Apollo 8 would go around the Moon at Christmas 1968. It would beat the Soviets to another first and help to reveal any problems in the Command Module that might affect the later LM lunar-orbit rehearsal. When it blasted off on 21 December, with a crew of Frank Borman, Jim Lovell, and Bill Anders, Apollo 8 was also the first manned Saturn V launch. Fortunately for NASA, it was an almost flawless mission, its effect on the watching world almost as great as Armstrong and Aldrin's first steps on the Moon would be a few months later. With everything going well, the crew were given the go-ahead for the crucial engine burn that would put them into lunar orbit less than three days after leaving Earth. The burn had to take place over the Moon's far side, out of contact with Earth, and there was tension at Mission Control until the craft emerged, intact and in orbit, from its radio silence.

That Christmas, the astronauts became the first people to see Earthrise over the Moon, and to take in our fragile planet's isolation in space. The images they sent back were iconic, and matched with equally stirring words as they read the opening lines from the Bible's Book of Genesis – "In the beginning, God created the heavens and the Earth ..." – before wishing a Merry Christmas to the entire world.

BIOGRAPHY

FRANK BORMAN

Born in Indiana but raised in Arizona, Frank Borman (b.1928) began flying as a teenager. He graduated from the United States Military Academy in 1950 and served as a fighter and test pilot in the US Air Force before joining NASA in 1962. After flying on the Gemini 7 mission in 1965, he sat on the investigation board following the Apollo 1 fire, and then took command of Apollo 8. After leaving NASA and the USAF in 1970, he built a second career in the airline business, retiring in 1986 to enjoy his hobby of restoring and flying vintage aircraft.

AROUND THE FAR SIDE
The Apollo 8 crew (below) returned with the most detailed images yet from the lunar far side, including the spectacular Earthrise (above) and the dark-floored crater Tsiolkovskii (left).

SPIDER ABOVE THE EARTH
During day five of the Apollo 9 mission, McDivitt and Schweickart boarded the LM and practised separation and flying manoeuvres in Earth orbit. David Scott watched from the CSM and took this picture of the LM hanging above the horizon. It shows the legs in their unfolded position and the rarely seen surface probes extending out from each of the foot pads.

Apollos 9 and 10

By early 1969, the Apollo Lunar Module was finally ready for action, but there were still two crucial qualifying missions needed before the first attempt to put a man on the Moon.

DOCKED IN ORBIT
David Scott stands halfway out of the hatch of the Apollo 9 Command Module, 190km (118 miles) above the Earth. The body of the LM Spider dominates the foreground.

The history of spaceflight is full of "what ifs". If NASA had stuck with its original rosters, the crew of Apollo 9 should have flown on Apollo 8, circling the Moon at Christmas 1968. As it was, perhaps due to the fact that they had been training to fly the LM for more than two years, James McDivitt, David Scott, and Russell Schweickart were shifted back by one flight, lifting off with the first complete Apollo spacecraft on 3 March 1969, but destined to go no further than Earth orbit. With Apollo 8's lunar mission making plans for a further LM test in high Earth orbit redundant, this meant that there would be only one more mission – a dress rehearsal in lunar orbit – before the first landing attempt. It also put McDivitt's backup crew – led by Neil Armstrong – in line for a landing attempt aboard Apollo 11.

Gumdrop and *Spider*

Because the Apollo 9 spacecraft would be split in two for parts of the mission, NASA allowed the crew to choose individual callsigns for the CSM and LM – naming their spacecraft for the first time since Gemini 3. The LM was called *Spider* for obvious reasons, while the CSM was nicknamed *Gumdrop* after it arrived at Kennedy Space Center wrapped in blue cellophane. Throughout their ten-day mission, the Apollo 9 crew thoroughly tested both spacecraft, practising docking and undocking manoeuvres, flying the LM up to 179km (111 miles) from the CSM, and using both the ascent and descent engines in orbit. Schweickart also performed the first Apollo Spacewalk, testing the new spacesuit's integral life-support systems. Apart from a bout of space sickness for Schweickart, everything went well, and by the time the crew returned on 13 March, the Moon was almost within Apollo's grasp.

So far and so near

The final dress-rehearsal mission, Apollo 10, thundered into the skies above Cape Canaveral on 18 May, with the highly experienced crew of Thomas Stafford, John Young, and Eugene Cernan onboard. The flight to the Moon and injection into lunar orbit went without a hitch, and once in lunar orbit, Stafford and Cernan boarded the LM, named *Snoopy* after the dog in the popular *Peanuts* cartoon strip, and undocked from the CSM (named *Charlie Brown* after Snoopy's owner).

While Young remained in orbit high above the Moon, his colleagues flew the LM to within 16km (10 miles) of the lunar surface with no major problems, snapping high-resolution photographs of the Sea of Tranquillity, by now selected as the target for Apollo 11. After their close encounter with the Moon, they reunited with the CSM, discarded the LM, and prepared for the long voyage home.

By the time Apollo 10 returned to Earth four days later, even Soviet cosmonaut trainer Nikolai Kamanin was privately admitting that, barring disaster, the Americans would be on the Moon within weeks.

24 January 1969
The first of the Apollo Lunar Modules is finally approved for flight as part of the Apollo 9 mission.

3 March 1969
Apollo 9 launches on a ten-day mission in orbit above the Earth.

7 March 1969
The LM is flight-tested alone in Earth orbit.

13 March 1969
Apollo 9 makes a safe return to Earth.

18 May 1969
Apollo 10 launches on its dress-rehearsal mission to the Moon.

21 May 1969
Apollo 10 goes into lunar orbit.

22 May 1969
Aboard the LM *Snoopy*, astronauts Cernan and Stafford come within 16km (10 miles) of the lunar surface.

26 May 1969
The Apollo 10 Command Module splashes down in the Pacific Ocean.

9 June 1969
In the wake of Apollo 10's success, NASA confirms that Apollo 11 is on schedule for launch on 16 July.

LUNAR SEPARATION
The Apollo 10 LM Snoopy separates from the Command Module. Onboard, Cernan and Stafford begin tests of the LM's independent performance.

CLOSE TO THE SURFACE
After a 27-second engine burn, the LM has entered an elliptical orbit, with an altitude ranging from 113km (70 miles) to 15.6km (9⅔ miles) from the Moon's surface.

MISSION COMPLETED
Snoopy returns from its expedition, reuniting with Charlie Brown. So far as it went, the mission was a complete success, though the LM was not equipped for a landing.

1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992

Voyage to the Moon

The world watched in awe as Apollo 11 sped towards the Moon in mid-July 1969. Now the Space Race was no longer with the Soviet Union, but with Kennedy's self-imposed deadline – and NASA's own good fortune.

16 July 1969
Apollo 11 launches from Cape Canaveral on its way to the Moon. Within two hours, it is out of Earth orbit and on its translunar flightpath.

17 July 1969
Michael Collins takes star sightings to compare Apollo 11's theoretical flightpath to its actual one. A three-second mid-course engine burn corrects the trajectory

18 July 1969
The crew transmit a 96-minute guided tour of their spacecraft back to Earth, where it is broadcast live on television.

19 July 1969
Following a successful retro-rocket burn, Apollo 11 enters orbit around the Moon.

20 July 1969
The LM separates from the CSM and enters an orbit that spirals gradually closer to the Moon. Just over two hours later, *Eagle* touches down in the Sea of Tranquillity.

At 09:32 local time on 16 July 1969, the huge S-IC first stage of a Saturn V rocket thundered into life on Pad A of Kennedy Space Center's Launch Complex 39. Five F-1 engines gradually throttled up to full power, consuming 13,000 litres (3,500 gallons) of liquid hydrogen and liquid oxygen every second. Explosive bolts blew, separating the rocket from its support structure, and the Saturn V slowly lumbered into the sky. A million people lining the nearby highways and beaches cheered as the rocket soared higher, rapidly gaining speed. An estimated 600 million television viewers around the world were watching with them. Within 12 minutes, Apollo 11 was in orbit.

The spacecraft's crew – Commander Neil Armstrong, Lunar Module Pilot Buzz Aldrin, and Command Module Pilot Michael Collins – had fallen into the frame for the first lunar landing when the decision was made to send Apollo 8 around the Moon (see p.134). They had since been subjected to the most intensive training of their careers, and ferocious media scrutiny. By the time they walked to the pad that fateful morning, they were ready for almost anything. As a crew, they were not socially close – Collins was the most personable, Aldrin perhaps the most intense, while Armstrong had the remote brilliance of a top-gun test pilot. Nevertheless, all were consummate professionals, and as the training instructors conspired to throw countless disaster scenarios at them, they reached a point where each could trust the others with his life.

BIOGRAPHY

NEIL ARMSTRONG

Ohio native Neil Alden Armstrong (b.1930) studied aerospace engineering on a naval scholarship from 1947, as part of which he began service as a US Navy pilot in 1949. After training, he saw action in the Korean War before returning to complete his degree, and upon graduation he applied to become a test pilot for NACA and later NASA. He applied for the second astronaut intake in 1962, and was on the backup crews for Geminis 5 and 11, as well as commanding Gemini 8 (see p.108). After backup duties on Apollo 9, Apollo 11 was his last spaceflight. He worked on the Apollo 13 inquiry before leaving NASA in 1971 to pursue interests in business and education. He also served on the commission investigating the loss of *Challenger* in 1986 (see p.202–203).

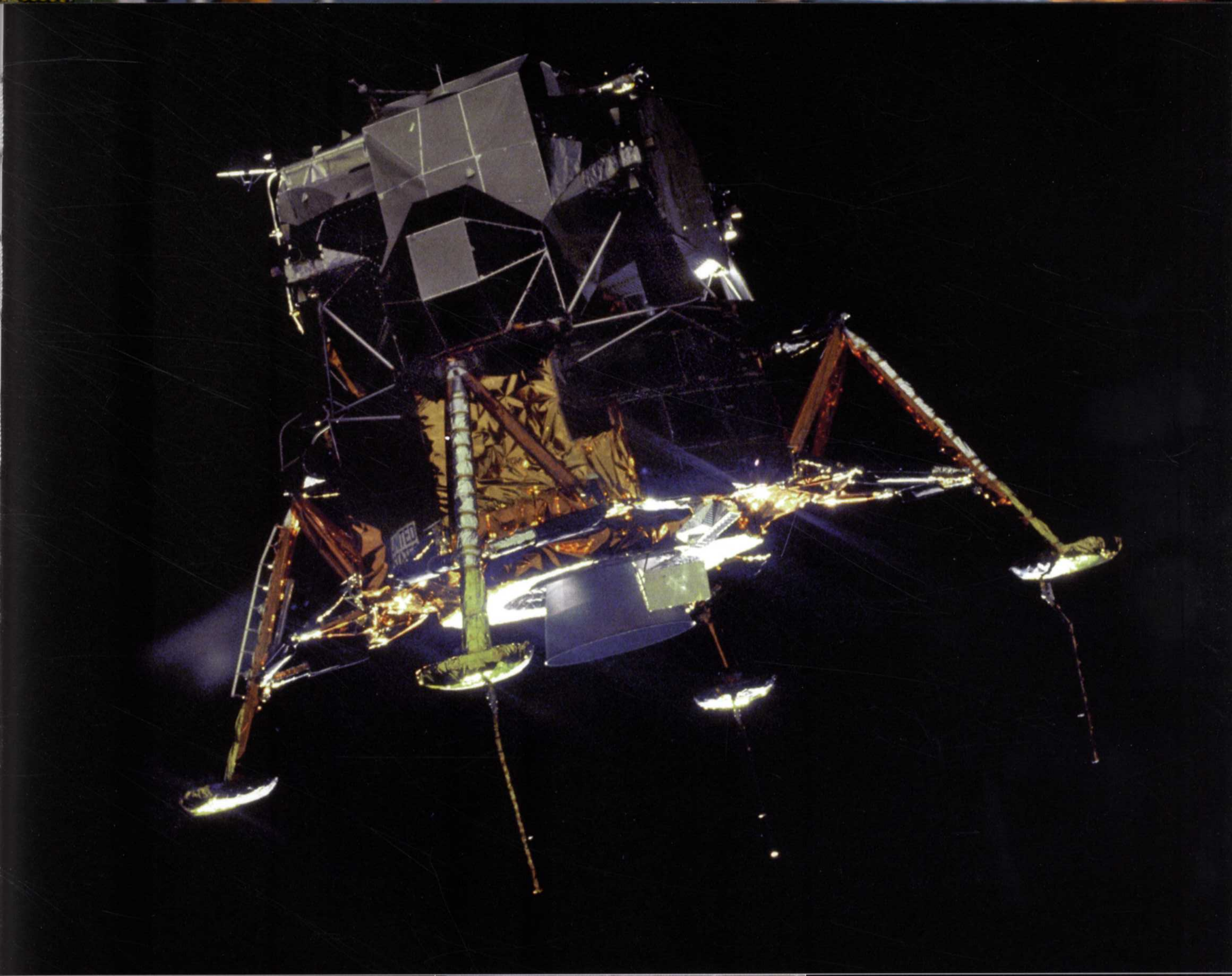
En route to history

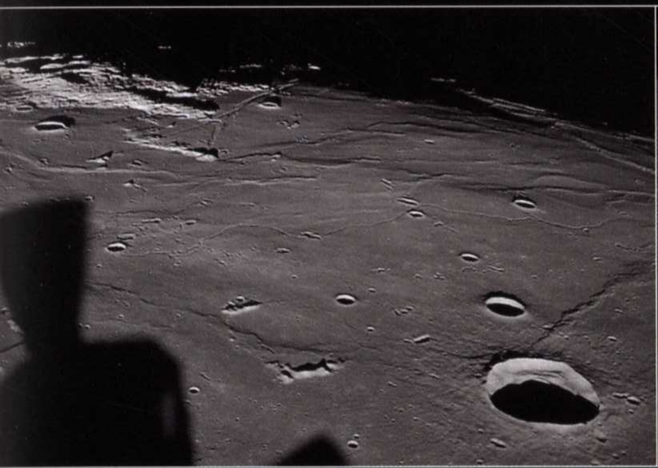
After just one-and-a-half orbits of the Earth, the S-IVB upper stage kicked the spacecraft onto its translunar trajectory. Once safely on its way, the CSM *Columbia* eased free of the rocket stage, turned through 180 degrees, and docked with the LM *Eagle*, which had nestled beneath it during the launch.

Safely freed from the rocket, Apollo 11 sped on towards the Moon. The journey took a little over three days – then came the vital retro-rocket burn to slip into lunar orbit and the preparations for separation of the LM and CSM. Twenty-five hours after arrival, a 30-second burn on *Eagle*'s descent engine dropped it into an orbit that took it within 13km (8 miles) of the surface. Inside the LM, Armstrong and Aldrin stood side by side, held in place by elastic stays. Face-down to the surface, they watched the landscape roll past beneath them until Houston gave the final go-ahead to land. Now Armstrong used a fine-guidance controller to throttle the descent engines while Aldrin read the module's altitude and fuel. Both astronauts stared out of the windows, looking for a smooth area to land. Spotting a dusty plain, Armstrong eased the spacecraft down, making contact with the surface with barely 20 seconds of descent fuel remaining.

***EAGLE* IN ORBIT**
Michael Collins took this photograph of Apollo 11's Lunar Module as it began to draw away from his CSM on the long spiral down to the Moon. The LM executed a complete rotation outside the CSM's windows, while Collins looked for any signs of damage inflicted by the stresses of launch.

MAKING HISTORY
Work in Mission Control is all but forgotten as the controllers turn from their desks to watch pictures of the first Moon landing coming back from Apollo 11.





20–07–69 17:44 GMT

Shortly after separation, Armstrong and Aldrin pass over their target – "Landing Site 2" in the Sea of Tranquillity. In this photograph, it lies just to the right of centre on the edge of the retreating night shadow.

20–07–69 19:08 GMT

Looking back at the CSM from their elliptical orbit, the LM astronauts can see it against the lightly cratered Sea of Fertility. At the lowest point in their orbit, Armstrong triggers the engines and the LM begins its final descent.

20–07–69 20:17 GMT

The astronauts soon realize they are landing several miles off target. As the automatic descent is heading for a field of large boulders, Armstrong takes manual control, bringing the LM down in a smoother area.

DESTINATION MOON
On the morning of 16 July 1969, Apollo 11's Saturn V launch vehicle lumbers clear of its own exhaust flames at the beginning of an epic 1.5-million-km (950,000-mile) voyage.

The Eagle has landed

Three days after their spectacular launch from Cape Canaveral, the Apollo 11 astronauts were ready to take the first human steps on another world.

21 July 1969
Neil Armstrong becomes the first person to step onto the surface of the Moon. He and Buzz Aldrin complete a spacewalk lasting just over two hours. The LM lifts off from the lunar surface 12 hours later, and docks safely with the CSM in lunar orbit.

22 July 1969
The LM and CSM separate in lunar orbit, and the CSM makes a successful transfer back into a trans-Earth orbit. Later in the day, a small mid-course correction burn is needed.

24 July 1969
The Command and Service modules separate at 16:21 GMT, and the Command Module re-enters the Earth's atmosphere, splashing down at 16:50. Little more than an hour later, the astronauts are aboard the recovery ship.

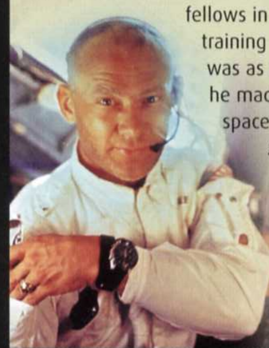
10 August 1969
The crew emerge from quarantine.

As *Eagle* settled onto the Sea of Tranquillity, the astronauts waited, tense, to see what effect the weight of the capsule would have on the rocks and dust below. Fortunately, the lander's pads settled barely an inch into the soil. Relaxing briefly, Armstrong and Aldrin stopped for a meal before it was time to don their spacesuits. Getting out of the LM while burdened by the suit and its backpack was difficult, even though the lower gravity reduced the weight of suit and pack from 86kg (190lb) to just 14kg (30lb). Armstrong stepped out first, shuffling backwards through the hatchway and climbing down the ladder, pausing to deploy the television camera that would send pictures back to the billion or more people watching on Earth. He finally stepped onto the Moon at 02:56 GMT on 21 July 1969.

Aldrin followed 19 minutes later, and for just under two hours, both astronauts collected rock samples, deployed science experiments, and tested conditions in the reduced gravity. They filmed their entire expedition (though only black-and-white television pictures could be relayed live back to Earth) and attempted to describe their surroundings in an effort to pin down their location – they had clearly landed several miles from their intended site. One curiosity they noted was the difficulty of estimating distance – the lunar horizon was much closer than Earth's, and without an atmosphere there was no haze to offer a visual clue to the distance and scale of the nearby hills.

BIOGRAPHY

BUZZ ALDRIN

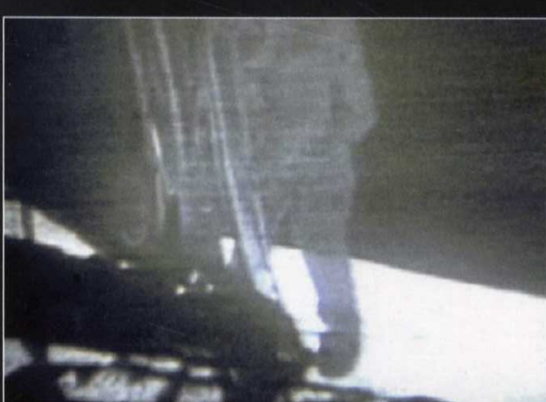


Born and raised in New Jersey, Buzz (formerly Edwin) Aldrin (b.1930) served in the US Air Force during the Korean War before studying for a doctorate in astronautics, for which he wrote a thesis that earned him the nickname of Doctor Rendezvous among his fellows in NASA's third astronaut training group. His first mission was as backup on Gemini 9, and he made the first truly successful spacewalk on Gemini 12. After Apollo, he returned to the Air Force, but struggled with personal problems. Today, he is known as an author and advocate of manned spaceflight.

They also placed a flag, a plaque, and artefacts commemorating the lost astronauts of Apollo 1 and Soyuz 1, and they had a brief conversation with US President Nixon.

All too soon, it was time to return to the LM, first loading aboard a precious 22kg (48lb) of rock samples from the area around their landing site. Back aboard the LM, Armstrong and Aldrin shed their spacesuits, ate a meal, and attempted to sleep, stringing up hammocks across the interior of the LM. They were the first to discover that contamination with lunar material was unavoidable – the fine dust

ALDRIN STEPS OUT
Buzz Aldrin poses in front of the LM during the Apollo 11 EVA. To his right is the flag-like collector of the Solar Wind Composition Experiment.

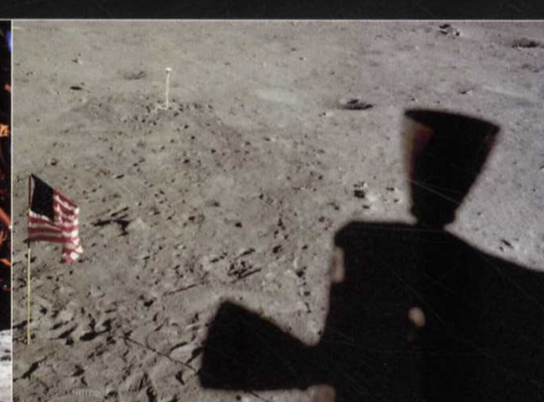


21-07-69 02:56 GMT

Neil Armstrong steps from the LM ladder onto the lunar surface – an event recorded only by the monochrome television camera mounted on the side of the module.

21-07-69 03:15 GMT

Nineteen minutes later, Buzz Aldrin steps out to join Armstrong on the Moon. This time, Armstrong is on hand to take a high-quality 70mm photograph.



21-07-69 17:54 GMT

As the LM lifts off from the lunar surface, the American flag, planted a little too close to the lander, takes a buffeting from its exhaust.

"That´s one **small step** for (a) man; one **giant leap** for mankind."

Neil Armstrong, as he steps onto the Moon, 21 July 1969

of the lunar surface stuck to everything, and tasted and smelled rather like gunpowder. Twelve hours later, they fired *Eagle*'s ascent engine, breaking free of the LM's lower stage and launching themselves on a trajectory to rendezvous with Collins and the CSM in lunar orbit. With the two spacecraft safely docked, the first task was to increase the atmospheric pressure in the CSM, and vent the stale, dusty air from the LM – that way, when the hatch between them was opened, air would flow into *Eagle*, minimizing the amount of dust drifting the other way. Then Armstrong and Aldrin passed their samples and other equipment through to Collins, before drifting through themselves, and swiftly changing their clothes and packing their dusty overalls into airtight containers.

With the astronauts back aboard *Columbia*, the faithful *Eagle* was cast adrift in an orbit that would eventually see it crash into the lunar surface. A brief engine burn then launched the CSM on a return flight to Earth that took two-and-a-half days. Re-entry was flawless, and Apollo 11 splashed down in the Pacific Ocean on 24 July, just 24km (15 miles) from the USS *Hornet*, where President Nixon was waiting.

The mission was not quite over, though – the astronauts still had to endure nearly three weeks in quarantine, first in a cramped trailer aboard the recovery ship and then in more comfortable conditions at Houston. The day of their release, 10 August 1969, was celebrated with parades across America – the beginning of a 25-nation, 45-day world tour in celebration of their "Giant Leap".

TRIUMPHANT RETURN
Huge crowds greet the Apollo astronauts in New York on 13 August 1969. Later that day they would see similar celebrations in Chicago and Los Angeles.

EXPERIENCE

THE FIRST MOON LANDING

APOLLO MANIA
Businesses capitalized on the US triumph by producing a host of Apollo memorabilia.

One small step ...

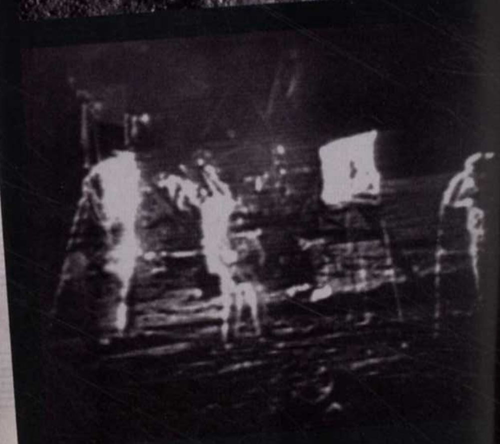
Six-and-a-half hours after the LM *Eagle* had touched down on the Moon, and watched by millions back on Earth, Neil Armstrong took his first historic steps onto the lunar soil. He was soon followed by Buzz Aldrin for a moonwalk lasting about two-and-a-half hours.

As they struggled into their bulky PLSS lift-support packs and readied themselves for the EVA, the astronauts were aware that they were running behind schedule. A series of strict checklists had been prepared during training on the ground, and although they followed these in minute detail, they found that there were many other issues to consider when doing it for real. Finally, at 02:30am, they opened the hatch. As Armstrong backed out onto the LM's "porch", and down the ladder, he paused to release the external television camera that would capture his first steps on the new world.

"I'm at the foot of the ladder. The LM footpads are only depressed in … about one or two inches … It's almost like a powder. Ground mass is very fine. I'm going to step off the LM now … **That's one small step** for (a) man, one giant leap for **mankind** … Yes, the surface is fine and powdery. I can kick it up loosely with my toe."

Neil Armstrong, 2:56am GMT, 21 July 1969

WALKING ON THE MOON
The astronauts spent some time in the LM studying their surroundings and deciding on the placement of experiments before they stepped outside. Aldrin passed a high-quality camera out to Armstrong, and the television camera was relocated from the LM to a tripod where it could capture most of their moonwalk in detail.

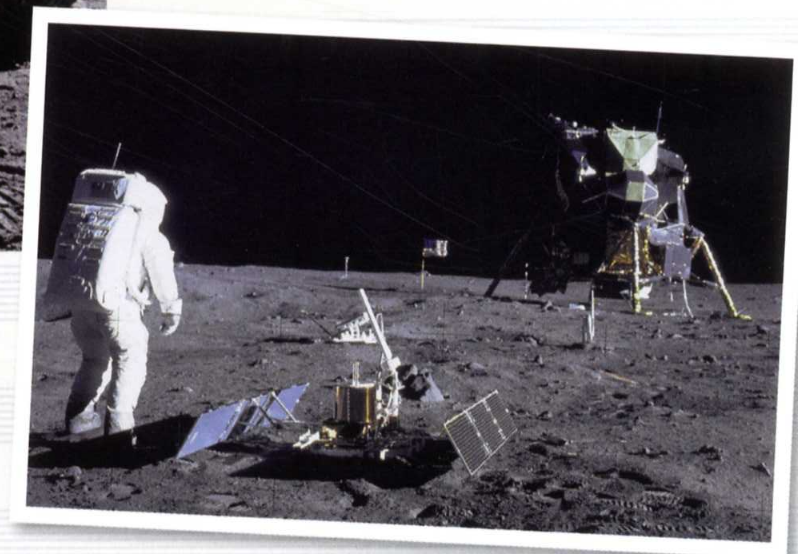


FOOTSTEPS IN THE DUST
Considering their weight on the Moon, the astronauts made quite deep prints in the lunar surface regolith. They are likely to remain for millions of years.

"Beautiful view! **Magnificent desolation.**"

Buzz Aldrin steps onto the Moon, 21 July 1969

TEST LANDING
Since this was the first lunar landing, one important part of the moonwalk was for the astronauts to inspect the condition of the LM and report back to Houston – fortunately, it had not suffered any damage in the landing.



AT WORK ON THE MOON
Towards the end of their moonwalk, Armstrong and Aldrin deployed the Early Apollo Scientific Experiments Package (EASEP), including a seismometer, an experiment to measure the build-up of lunar dust, and a solar-powered transmitter to send the results back to Earth.

Fifteen minutes later, Aldrin was on the porch and ready to join Armstrong, who was by now equipped with a high-quality Hasselblad camera. Once on the surface, he spent a little time analyzing different methods of getting around in the one-sixth gravity, finally concluding that a loping stride was the best solution. After Armstrong had relocated the television camera to a tripod, the astronauts planted the US flag together, and received a special transmission via Houston:

President Nixon: Hello, Neil and Buzz. I'm talking to you by telephone from the Oval Room at the **White House** ... For every American, this has to be the proudest day of our lives ... And as you talk to us from the **Sea of Tranquillity**, it inspires us to redouble our efforts to bring peace and tranquillity to Earth. For **one priceless moment** in the whole history of man, all the people on this Earth are truly one; one in their pride in what you have done, and one in our prayers that you will return safely to Earth.
Neil Armstrong: Thank you, Mr. President. It's a great honour and privilege for us to be here representing not only the United States, but men of peace of all nations.

Resuming work, the astronauts set up a package of experiments on the surface. Aldrin then collected a pair of core samples from the lunar soil, while Armstrong loped to the rim of a nearby crater to photograph their surroundings. They spent the remainder of their allocated time collecting and cataloguing rock samples, before first Aldrin, and then Armstrong, climbed back aboard the LM.

A MESSAGE TO THE FUTURE
The plaque on the leg of the LM descent stage, left on the Moon for posterity, reads: "Here men from the planet Earth first set foot upon the Moon, July, 1969 AD. We came in peace for all mankind".

"The blue colour of my boots has completely **disappeared** now into this ... **greyish-cocoa colour.**"

Buzz Aldrin at work on the Moon, 21 July 1969

Apollo 12

The second manned landing on the Moon offered an opportunity to refine the rough edges of the first mission, and to begin the scientific programme in earnest, with two much longer moonwalks.

14 November 1969
Apollo 12 is twice struck by lightning during its launch.

19 November 1969
The LM *Intrepid* touches down on the surface of the Moon in the Ocean of Storms. Conrad and Bean make their first moonwalk.

20 November 1969
The astronauts make a second moonwalk, visiting the landing site of Surveyor 3, before returning to orbit and redocking with the CSM *Yankee Clipper*.

21 November 1969
Yankee Clipper fires its engines to begin the return to Earth.

24 November 1969
The Apollo 12 Command Module splashes down in the South Pacific. During landing, a dislodged camera strikes Bean on the head and briefly knocks him out.

LIGHTNING STRIKES
Two bolts of lightning struck the Saturn V rocket during launch, scrambling the transmission of data from the spacecraft. Fortunately, quick-thinking flight controllers figured out a way to reboot the system and restore the flow of data.

It was only after the success of Apollo 11 that NASA drew up an itinerary of landing sites for later manned missions. Locations were chosen to provide rock samples and other data for a wide range of different lunar terrains. The target for Apollo 12, planned for launch later in the year, was to be the Ocean of Storms area.

There was another reason to visit this area – it had previously been targeted by the Surveyor 3 probe. Visiting an object that had been on the Moon for a known period of time (in this case some 30 months) could provide valuable information about present-day lunar conditions. The probe could also act as target for a pinpoint landing attempt – Apollo 11 had landed 6.5km (4 miles) from its planned target, and more precise landings would also be required for future operations.

BIOGRAPHY

ALAN BEAN

Texan-born Al Bean (b.1932) studied aeronautical engineering before joining the US Navy in 1955. He joined NASA in 1963, and was on the backup crew for Gemini 10, but was only added to the Apollo crew rosters after fellow astronaut Clifton Williams was killed in a jet crash during training. After training for the Apollo Applications Program, he commanded Skylab 3. Bean remained in NASA as an administrator until 1981, when he retired from the agency to become a full-time space artist.

Stormy voyage

Apollo 12 launched into thunderous skies above Cape Kennedy on 14 November 1969, with Pete Conrad, Richard Gordon, and Al Bean aboard. Aside from a scare during launch as lightning struck the spacecraft, the flight to the Moon went without a hitch, and on 19 November, Conrad and Bean boarded the LM *Intrepid*, leaving Gordon aboard the CSM *Yankee Clipper* in lunar orbit. Descent to the chosen landing site, nicknamed "Pete's Parking Lot", was initially automatic, but when the astronauts saw the area looked rougher than anticipated, Conrad took manual control and brought the LM down in a safe area nearby.

After five hours, Conrad stepped onto the surface. His first task was to collect and store a contingency soil sample in case some emergency forced a hasty departure. As Bean joined Conrad on the surface, both astronauts found themselves covered in a film of dust from the powdery rock.

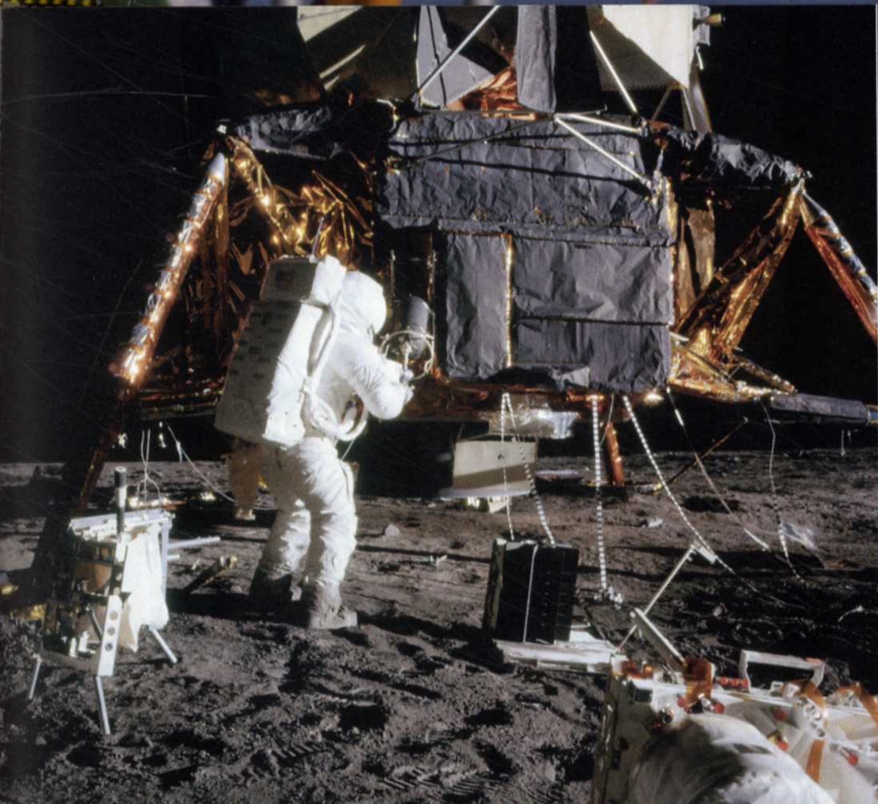
Working on the surface

Conrad and Bean made two separate moonwalks. The first was to set up scientific instruments around the LM – Apollo 12 and subsequent missions all carried an ALSEP (Apollo Lunar Surface Experiments Package) more comprehensive than the instruments deployed by Armstrong and Aldrin.

The next morning, the astronauts again stepped out on the surface, for a lunar hike of a little over 1km (⅔ mile) in total. They followed a route prepared by geologists back at Mission Control, collecting samples and answering questions from Earth as they went. Despite geological training, they admitted to finding it hard to fathom the history of the landscape around them. After two hours, they arrived at Surveyor 3, which they photographed before removing pieces for later analysis. Surveyor's television camera eventually proved to contain bacteria that had strayed into it back on Earth, and survived intact throughout their time on the Moon.

Intrepid and *Yankee Clipper* reunited in lunar orbit 37 hours after they had separated. Dick Gordon took one look at his crewmates and told them they were not coming aboard the CSM in their grimy state – so once the samples were transferred, Conrad and Bean had to strip naked and float through the hatch wearing only their headsets. *Intrepid* was then set free to plummet back onto the Moon, where the reverberations of its impact were picked up by the ALSEP seismometer for more than an hour. Eleven orbits later, *Yankee Clipper* fired its engines for the long, but uneventful, journey back to Earth.

IN THE COMMAND MODULE
Dick Gordon enjoys the relatively spacious confines of the Yankee Clipper *during Conrad and Bean's surface expedition. Gordon was able to spot both* Intrepid *and Surveyor 3 from orbit, confirming Conrad's pinpoint landing before the astronauts left the LM.*

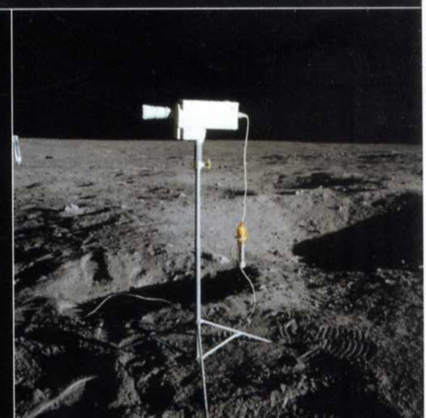


"**Whoopee!** Man, that may have been a small one for Neil, but it's **a long one for me!**"

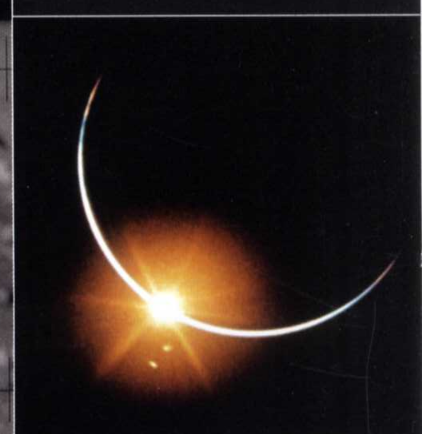
Pete Conrad, 11cm (4½in) shorter than Neil Armstrong, takes his first step onto the Moon

NUCLEAR ENERGY
Al Bean carefully extracts a Radioisotope Thermoelectric Generator (RTG) from its storage place in the Lunar Module. This was the first use on the Moon of an RTG – a simple electrical generator powered by radioactive decay.

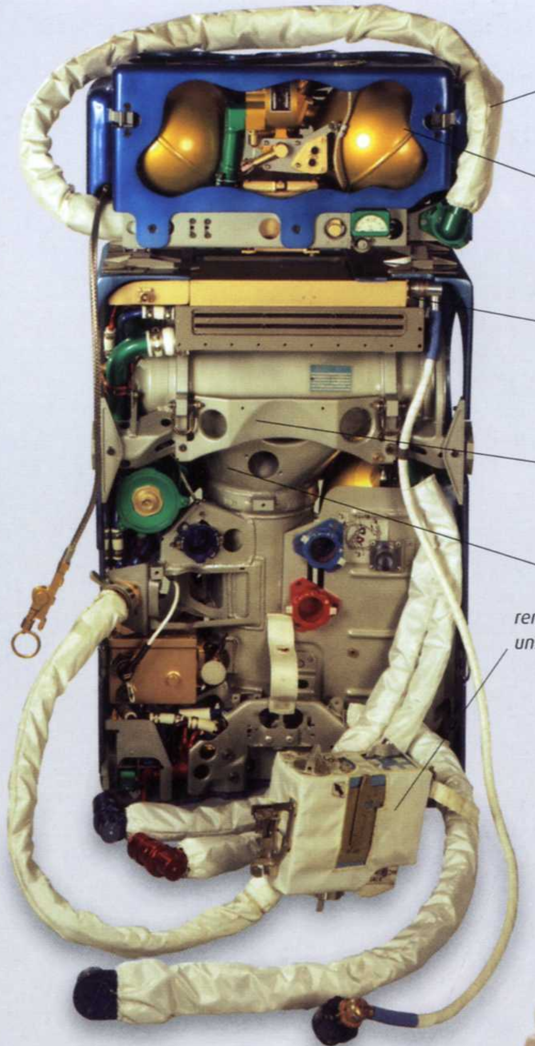
ON THE OCEAN OF STORMS
Al Bean poses for a photograph alongside a tool carrier during an Apollo 12 moonwalk. Pete Conrad can be clearly seen reflected in his visor (Bean's own camera is mounted on his chest control pack).



MINOR FAILURE
Plans to transmit colour TV pictures from the Moon were thwarted when the camera refused to work, burned out by accidental exposure to the Sun.



ECLIPSING THE SUN
On the way home, the astronauts captured this spectacular image as the Earth passed in front of the Sun.



BACKPACK
Apollo astronauts carried vital equipment in a bulky backpack called the Portable Life Support System (PLSS). This included pumps for the liquid cooling system, communications equipment, and water and oxygen supplies.

HEAD WEAR
Apollo headgear came in three parts – an outer helmet incorporating Sun shields and visors, an inner pressure helmet to preserve the astronaut's personal atmosphere, and a close-fitting skullcap with communications equipment.


Outer helmet


Pressure helmet


Communications cap

CUFF CHECKLIST
This checklist was worn by John Young on his Apollo 16 moonwalk. The pages shown describe how to collect rock samples.

TECHNOLOGY

A SURVIVAL SUIT FOR THE MOON

The Apollo spacesuit

Spacesuits for the Apollo missions had a number of differences from previous designs. They had to be more robust because of the extra risks that came with working on the surface of the Moon for extended periods, yet also more flexible and lighter because of the variety of tasks the astronauts might have to carry out and the need to operate in gravity rather than weightlessness. The solution was a basic spacesuit with optional extras that were worn during lunar excursions.

EXTRAVEHICULAR MOBILITY UNIT

The Apollo spacesuit or EMU had several layers. Closest to the skin was a liquid-cooled undergarment. Next came a nylon pressure garment to seal the astronaut from the vacuum of space, then several aluminium-coated layers for further heat protection.

DATE	1967
ORIGIN	United States
WEIGHT ON EARTH	86kg (190lb)
WEIGHT ON MOON	14kg (30lb)

SAMPLE COLLECTION

Astronauts used adapted tongs and a brush to collect samples from the Moon. To avoid contamination, samples were sealed inside containers before they were taken onboard the LM. They were reopened in a laboratory back on Earth.

Sample-return container

Brush

Tongs

GLOVES

Astronauts wore intravehicular gloves, such as this, inside the spacecraft. The inner layer was made from rubber and specially moulded for each astronaut.

WATCH

Despite regular timechecks from Mission Control, astronauts needed to keep their own track of time on the mission. Typically, they wore two Omega Speedmaster wristwatches – one set to Mission Elapsed Time, the other to GMT.

MOON BOOTS

The boots were the part of the suit in most danger from a puncture, so they came in two parts for extra safety. An overshoe protected the inner boot and could be discarded outside the LM to avoid bringing dust aboard the spacecraft.

Inner boot

Overshoe

Apollo 13

11 April 1970
Apollo 13 blasts off from Cape Canaveral on its way to the Moon

13 April 1970
An explosion cripples the CSM, which loses much of its air supply and the ability to generate power.

14 April 1970
Shortly after the explosion, the crew power up and board the LM, intending to use it as an escape lifeboat. Later in the day, they make a vital mid-course correction burn.

15 April 1970
Apollo 13 briefly loses contact with Earth as it passes over the far side of the Moon, some 254km (158 miles) above the lunar surface.

16 April 1970
A second mid-course engine burn accelerates Apollo 13's return.

17 April 1970
The Apollo 13 crew board the Command Module and make a successful re-entry and splashdown in the Pacific Ocean.

After two successful missions, the American public was starting to take the Moon for granted. But when an explosion struck Apollo 13 in April 1970, the world was gripped by the drama.

Shortly after launch, the crew of Apollo 13 settled in for a long translunar flight. For this mission, veteran astronaut Jim Lovell was joined by first-timers Fred Haise and Jack Swigert (a late substitute for Ken Mattingly, who had been exposed to German measles). Everything was going well until, some 56 hours into the flight and with the spacecraft already closer to the Moon than the Earth, the crew triggered a routine stir of the CSM's oxygen tanks. There was the sudden thump of an explosion in a vacuum, and the astronauts were alarmed to see pressure in one of the main oxygen tanks dropping and electrical power to the CSM rapidly failing (see over). With masterful restraint, Swigert famously reported "Okay, Houston, we've had a problem here."

PROBLEMS FROM THE OUTSET
Pogo oscillations (see p.119) caused one of the second-stage engines to cut out during launch, forcing the others to burn longer.

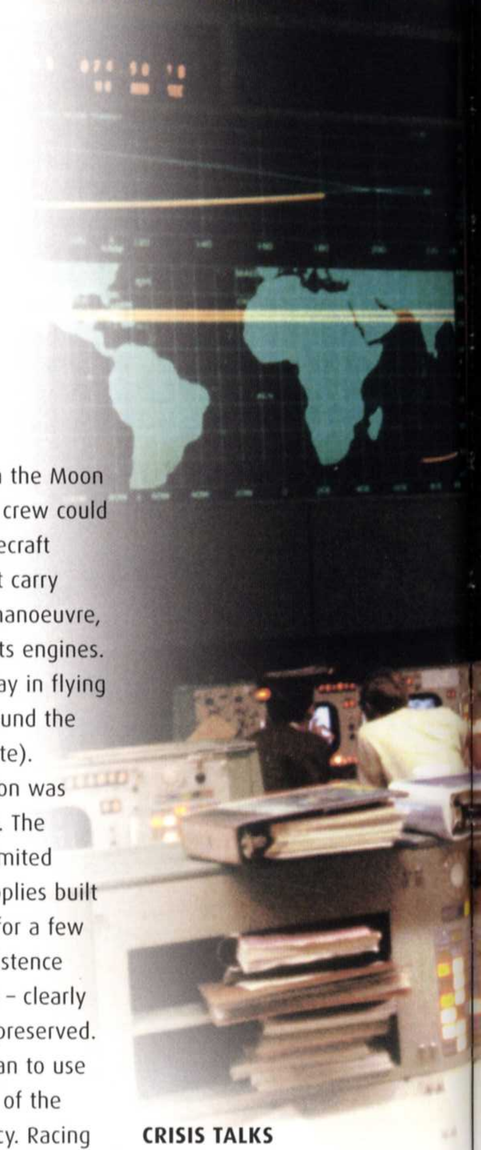
In fact, the astronauts and their controllers knew very well that the "problem" was life-threatening. The Service Module was clearly crippled, unable to provide power or oxygen to the Command Module. All thought of landing on the Moon was abandoned, but the crew could not simply turn the spacecraft around – the CSM did not carry enough fuel for such a manoeuvre, even if it could still fire its engines. The way back to safety lay in flying onwards and looping around the Moon (see panel, opposite).

The immediate question was how to survive that long. The Command Module had limited batteries and oxygen supplies built into it, but only enough for a few hours of independent existence during and after re-entry – clearly these would have to be preserved.

Fortunately, NASA had a contingency plan to use the LM, attached but dormant at the front of the CSM, as a lifeboat in this kind of emergency. Racing against time, the crew powered up the LM *Aquarius*, moved supplies into it, and sealed themselves in, switching off nearly all systems on the CSM *Odyssey* to conserve what little power remained.

Getting back to Earth

While the astronauts suffered in the cramped conditions aboard an LM designed to accommodate just two men for two days, Houston ground controllers led by Gene Kranz (see p.100) feverishly calculated their path back to safety. Conditions on *Aquarius* soon became cold and damp, but more problematically the chemical filters designed to

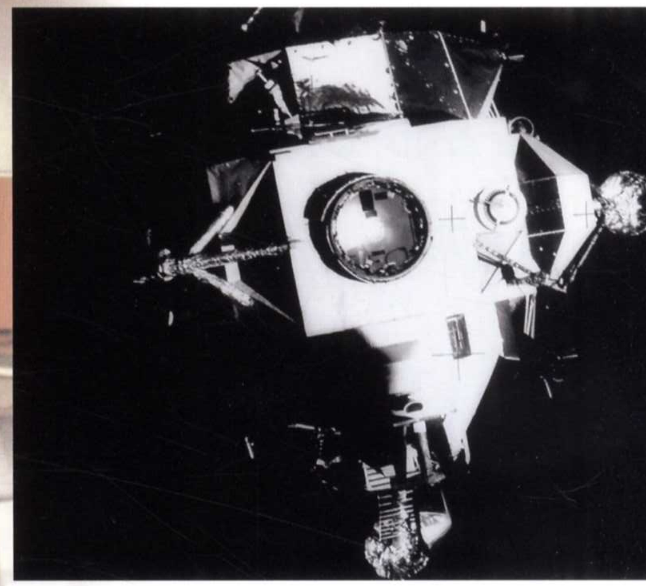


CRISIS TALKS
Apollo 13 Lunar Module Pilot Fred Haise talks with the Mission Operations Control Room at Houston during the crew's final television transmission, shortly before they boarded the LM. Gene Kranz is in the foreground with his back to the camera, wearing a distinctive white waistcoat.

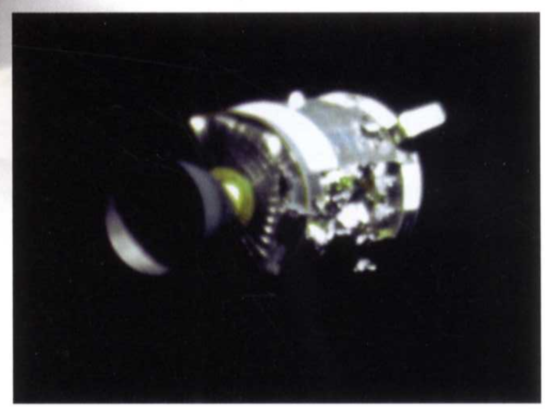
WAVING GOODBYE
Jim Lovell leads Jack Swigert and Fred Haise to the van for transfer to the Apollo 13 launch pad, little knowing the perils that await in space.

"Flight control will **never lose an American in space**. You've got to believe ... that this crew is coming home."

Gene Kranz, briefing mission controllers at Houston



LIFEBOAT AQUARIUS
The Apollo 13 crew, now aboard the Command Module, took this snapshot of their trusty LM as it drifted away from them shortly after separation on the final approach to Earth.



EXPLOSION DAMAGE
After abandoning the Service Module, the crew were able to see how the explosion had blown out one side of the module. The fault was eventually traced to poorly insulated wiring.

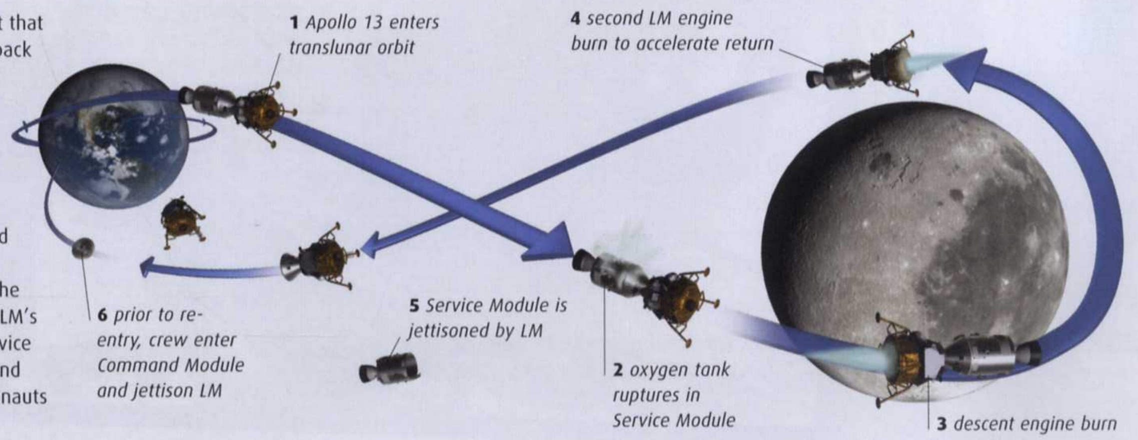
remove toxic carbon dioxide from the air were near exhaustion. Using simulators at Houston, Mattingly (who had not, after all, fallen ill) and the others found a way to convert the incompatible filters from the CSM for use on the LM, using only materials the astronauts had to hand. With no access to the CSM engines, the crew had to improvise their course-correction burns, calculating their precise position and trajectory by the stars and using the descent engine on the LM as a retrorocket for the entire spacecraft. A passage behind the Moon put the spacecraft on a return course for Earth, and the crew were able to re-enter the Command Module on 17 April as they approached Earth.

Fortunately, the Command Module separated without problems and, as millions of television viewers around the world held their breath, the crew splashed down safely in the Pacific Ocean.

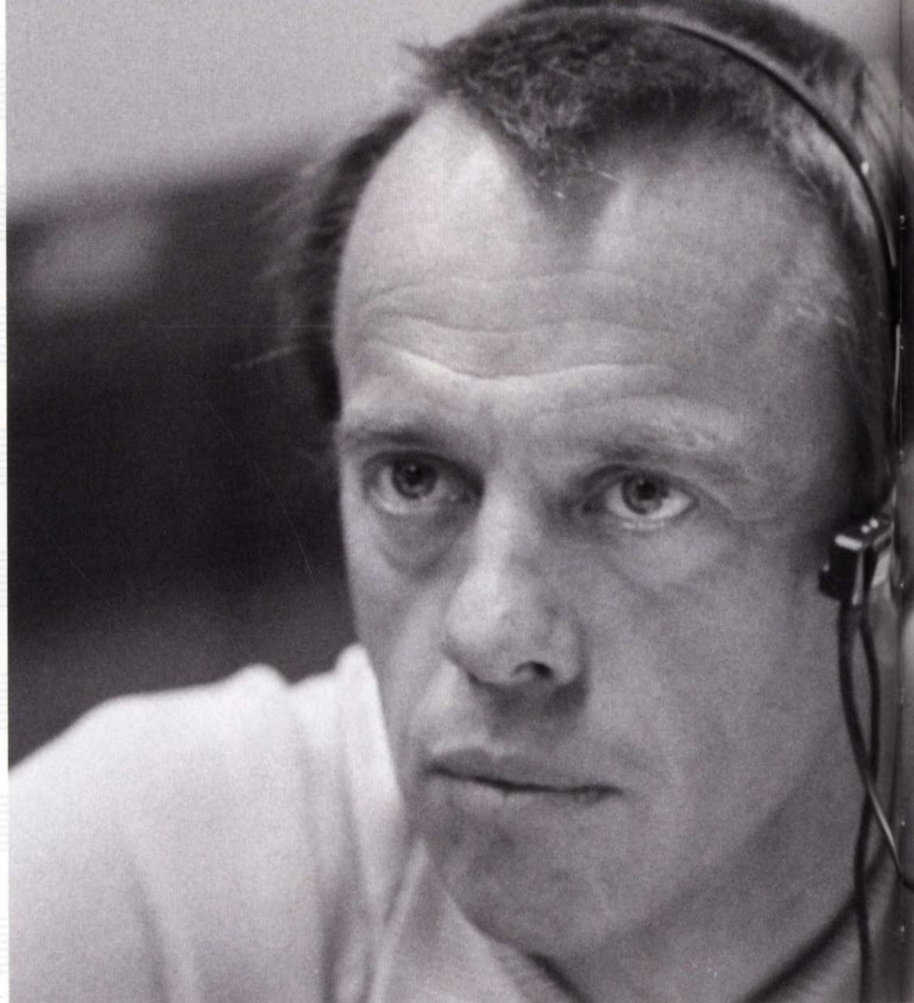
TECHNOLOGY

AROUND THE MOON TO SAFETY

The mission controllers at Houston soon worked out that the only way of bringing the Apollo 13 astronauts back to Earth was through a daring manual engine burn. This would put them into a free return trajectory – an orbit that would use the Moon's gravity like a slingshot, effectively catching the spacecraft, swinging it around the far side, and throwing it back towards the Earth without the need for a long engine burn. Nevertheless, some thrust was needed to adjust Apollo 13's approach to the Moon, and because there was no way of knowing how badly the CSM engine might be damaged, the burn used the LM's descent engine instead. Approaching Earth, the Service Module was, unusually, jettisoned with the Command Module still attached to the LM. This gave the astronauts a chance to photograph the damage.



"Houston, we've had a problem …"



Two days and eight hours into their mission, and more than 320,000km (199,000 miles) from Earth, the crew of Apollo 13 were thrown into crisis as an explosion left them with a crippled Service Module and a deteriorating oxygen and power supply. Their immediate response was crucial to their chances of survival.

On the evening of 13 April 1970, the crew of Apollo 13 broadcast a guided tour of their spacecraft back to Earth. Five minutes after transmission ended, they were still scattered through the spacecraft. Command Module Pilot Jack Swigert was in the CM, Lunar Module Pilot Fred Haise in the LM (specially opened for the tour), and Commander Jim Lovell in the tunnel between the two, helping Haise to close up the LM. Jack Lousma, on shift as Capcom at Houston, relayed a few routine requests – NASA wanted them to photograph Comet Bennett, and the engineers wanted some data on the high-gain antenna. Swigert reeled off the data from the instrument panels in front of him. The next request was to stir the tanks of low-temperature cryogenic oxygen – a routine procedure that prevented impurities in the liquid from settling to the bottom of the tank. As Swigert activated the stirring motor, a loud bang was heard throughout the spacecraft. Lovell looked accusingly at Haise – during the TV show he had startled them by triggering a repressurization valve that made a similar noise. But Haise's expression was deadly serious. The communications transcript records the moment:

Capcom: 13, we've got one more item for you, when you get a chance. We'd like you to stir up your cryo tanks. In addition, I have shaft and trunnion … for looking at the Comet Bennett, if you need it.

JS: Okay. Stand by.

JS: Okay, Houston, we've had a problem here.

Capcom: This is Houston. Say again, please.

Jim Lovell: Houston, we've had a problem. We've had a main B bus undervolt.

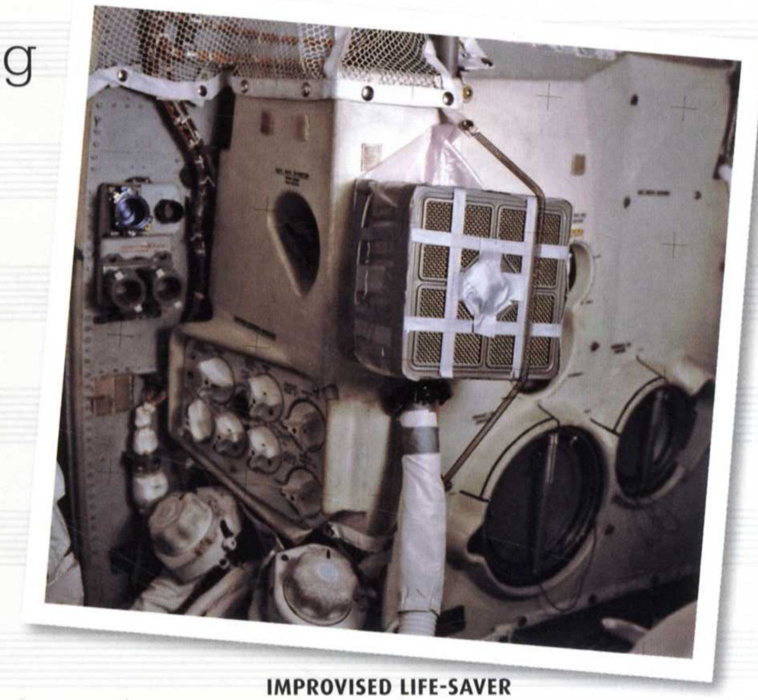
Capcom: Roger. Main B undervolt.

Capcom: Okay, stand by, 13. We're looking at it.

Fred Haise: Okay. Right now, Houston, the voltage is – is looking good. And we had a pretty large bang associated with the Caution and Warning there. And if I recall, main B was the one that had had an amp spike on it once before.

"It looks to me, looking out the hatch, that we are venting something. We are venting something into the – out into the space"

Jim Lovell in the aftermath of the accident



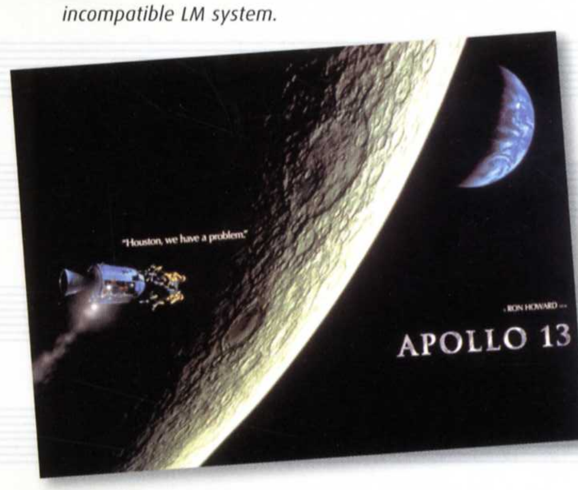
IMPROVISED LIFE-SAVER
As carbon dioxide built up in the LM, Mission Control told the astronauts how to build a "mailbox" device that would allow them to use chemical scrubbers from the Command Module in the incompatible LM system.

LUCKY ESCAPE
Alan Shepard, who might have commanded Apollo 13 but for his ear problem, listens in to the unfolding drama at Mission Control.

The "main bus undervolt" that flashed in the CM meant that one of the Service Module's power circuits was rapidly draining. As the crew struggled to reconcile the readings of their own instruments with the telemetry received on the ground, they realized that one of their two oxygen tanks was empty, and two of their three fuel cells were running flat. While staff at Houston frantically tried to work out what was happening, Lovell concentrated on stabilizing the spacecraft as it bucked from side to side. Peering out of the tiny CM windows, he spotted something that dashed his hopes of landing on the Moon – a jet of gas issuing from the side of the Service Module.

"Okay, Aquarius ... down here we're **getting regrouped**, trying to work on your control modes and ... taking a look at consumables as opposed to flight plan, and so forth, and as soon as we get all that information, we'll **pass it up to you**. We also have the 14 backup crew over in the simulators looking at dock burns and also trying to see what kind of alignment procedure they can come up with for **looking at stars** out the window. So if you ever are able to see any stars out there and think you can do an alignment ... why [not] let us know?"

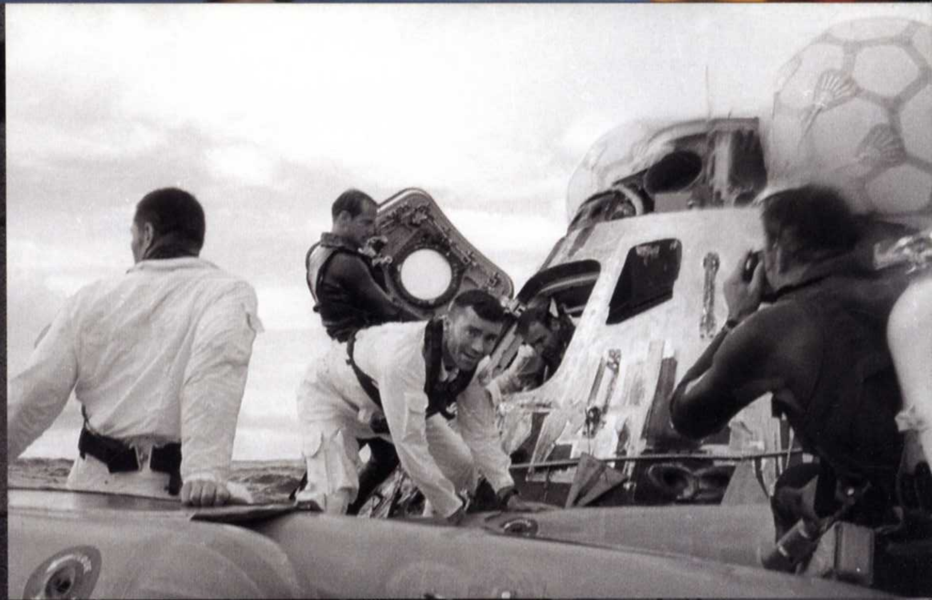
Jack Lousma, Apollo 13 Capcom



IMMORTALIZED ON CELLULOID
Ron Howard's acclaimed 1995 film, Apollo 13 *stuck closely to the actual sequence of events and helped to reignite popular interest in the Apollo missions.*

WORKING TOGETHER
Staff from all four Mission Control shifts collaborated to get the astronauts home. Pictures from the spacecraft were soon cut for power reasons, and the team had to rely on voice communications only. This made it even more difficult to relay instructions for building the "mailbox" filter that would keep the crew's air breathable.

Worse was to come, as the crew realized that pressure in the second oxygen tank was now also slowly dropping. The problem now became clear – the explosion had created a major rupture in the fuel cell system, into which they were still pumping precious oxygen. Not wanting to risk anything that might worsen the condition of the Service Module, Houston now sent Lovell and Haise back to the LM in an attempt to draw power from it. However, this idea was rapidly abandoned in favour of a lifeboat procedure – transferring the crew and their consumables to the LM *Aquarius* and powering down the CSM completely in order to swing around the Moon and back to Earth. Within three hours of the explosion, the crew of Apollo 13 were aboard *Aquarius* and ready for the long trip around the Moon and back to safety.



RETURN TO EARTH

(Left) Odyssey splashed down in the Pacific Ocean at 12:07pm Houston time on 17 April. The sight of its return was greeted with jubilation in a Mission Control packed with NASA personnel including (in the front row, from left) Apollo 13 Flight Directors Gerald Griffin, Gene Kranz, and Glynn Lunney.

SAFE AND SOUND

Navy divers were first to the scene, helping the crew aboard a life raft (top), while, back at Mission Control, Gene Kranz allowed himself a well-deserved cigar (middle). Within an hour of splashdown (from left) Haise, Swigert, and Lovell were being welcomed aboard the USS Iwo Jima (bottom).

Apollo 14

After the near-disaster of Apollo 13, NASA's next mission was vital to restoring its own confidence, and the prestige of the US space programme. Fortunately, it was a resounding success.

2 September 1970
NASA abandons plans for Apollos 15 and 19 in the face of budget cuts.

24 November 1970
Robert Gilruth reports that all recommendations of the Apollo 13 Review Board have been implemented.

31 January 1971
Apollo 14 blasts off. After some trouble docking with the LM, it makes a successful burn to put it on course for the Moon.

4 February 1971
Apollo 14 enters into lunar orbit.

5 February 1971
The LM *Antares* lands in the Fra Mauro area of the Moon. Alan Shepard and Ed Mitchell make their first moonwalk.

6 February 1971
The astronauts make a second moonwalk, and later take off from the lunar surface to reunite with the CSM for their return to Earth.

9 February 1971
The Apollo 14 Command Module splashes down in the Pacific Ocean.

TEEING OFF
As he returned from the second moonwalk, Shepard surprised everyone by producing a couple of smuggled golf balls and a club fashioned from various lunar tools. The first golf stroke on the Moon was a slice, but the second sent the ball for several hundred metres – the low gravity probably helped, since Shepard could use only one hand.

By the time Apollo 14 launched, on 31 January 1971, NASA had been away from the Moon for more than a year. During the hiatus, two more missions – the original Apollos 15 and 19 – had been lost to budget cuts, but Apollo 13's landing site at Fra Mauro, on the edge of the Oceanus Procellarum, was still a scientific priority, and so Apollo 14 was directed there instead. Leading the crew was a true veteran of the space programme. Alan Shepard, grounded since his historic *Freedom 7* flight, had undergone painful surgery to correct his ear problem, and Deke Slayton saw to it that his old Mercury Seven colleague would go to the Moon. Shepard's crewmates – Stuart Roosa and Edgar Mitchell – were both rookies.

Although launch and departure from Earth orbit went well, Apollo 14 hit a significant snag on its way to the Moon. As Shepard attempted to join the CSM *Kitty Hawk* to the Lunar Module *Antares*, the docking mechanism persistently failed to engage. Fortunately, it took on the sixth try. More problems dogged the LM's final descent, and Shepard's first words on the surface seemed doubly appropriate: "... it's been a long way, but we're here."

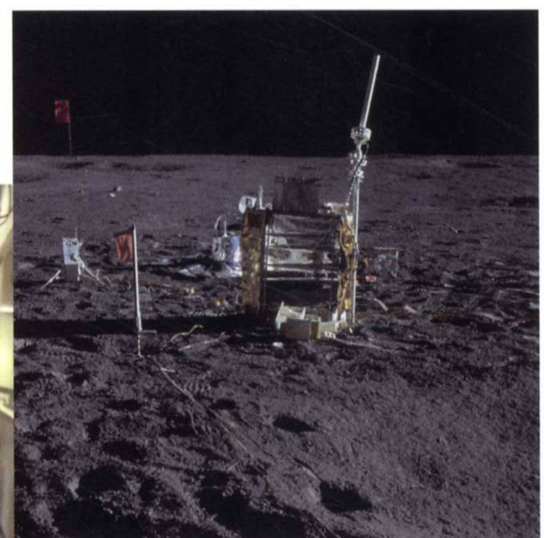
Shepard and Mitchell remained on the Moon for 33 hours, during which they made two long moonwalks. After collecting their contingency sample of rock, they set up the ALSEP and other experiments that would remain on the surface. The astronauts also investigated the lunar regolith using a device that fired "thumper" charges into the ground. The way these were detected by the ALSEP seismometers revealed properties of the ground in the area.

Lunar expedition

The second moonwalk was a "geology traverse" similar to that carried out on Apollo 12. The astronauts were asked to inspect the 300m- (1,000ft-) high rim of the nearby Cone Crater and found the climb up its outer flanks quite arduous even in one-sixth Earth gravity – especially as they were also towing a lunar cart called the Mobile Equipment Transporter (MET) with them. As they approached the rim, the terrain grew increasingly steep and hilly, and frustratingly they could not find the crater edge itself. After much debate, they turned back, not realizing until later that they had come within about 30m (100ft) of their goal.

On their return to Earth, the astronauts had to endure the same fortnight of quarantine suffered by their earlier colleagues. After they too failed to show any signs of unexpected illness, the practice was discontinued for later missions.

TENSE MOMENTS
Screens in the Mission Operations Control Room at Houston show the view from Kitty Hawk *during its repeated attempts to dock with* Antares *in Earth orbit. The top of the LM can be made out, still inside the S-IVB upper stage.*



ALSEP EXPERIMENTS
The astronauts laid out the various ALSEP experiments according to a map carried on their cuff checklists. The box in the centre is a detector for charged particles from space, while red flags mark geophones used to detect sound waves from the "thumper" experiment.

ANTARES AT REST
Ed Mitchell named the LM Antares *after the bright star most likely to be visible during the descent from orbit. The module landed on the edge of a depression and came to rest tilted over at an angle of 8°.*

26 July 1971
Apollo 15, first of the J-class Apollo missions, launches from Cape Canaveral.

29 July 1971
The spacecraft enters lunar orbit.

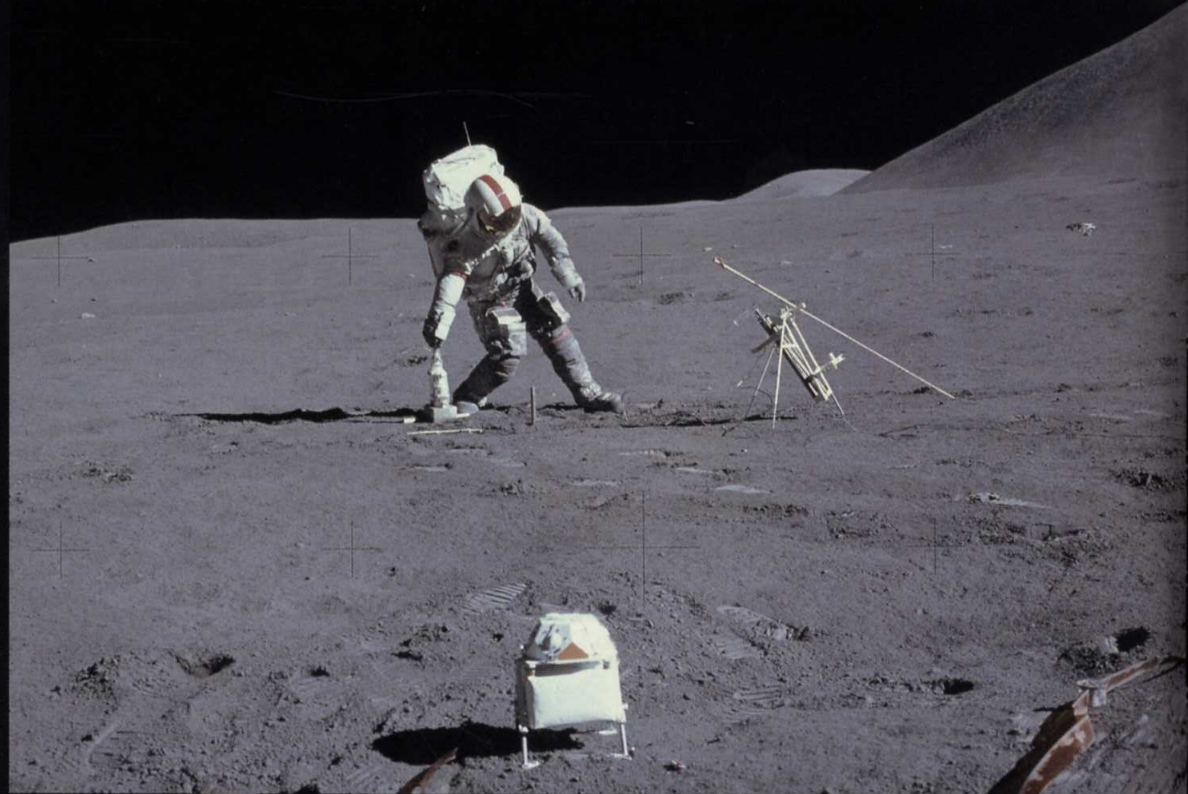
30 July 1971
The LM *Falcon* touches down on target close to Hadley Rille and the Lunar Apennine mountains.

31 July 1971
David Scott and James Irwin make the first of three expeditions onto the lunar surface. The LRV is used on the Moon for the first time.

2 August 1971
After a third moonwalk, Scott and Irwin lift off and return to the CSM in lunar orbit.

4 August 1971
Apollo 15 leaves lunar orbit on the return journey to Earth.

5 August 1971
Al Worden performs the first spacewalk beyond immediate Earth orbit, retrieving film and experimental data from the CSM's instrument bay.

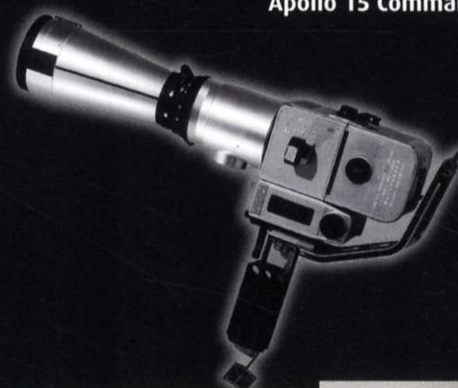


DRILLING THE MOON
David Scott picks up a cordless drill during his lengthy efforts to make holes for the probes of the Apollo 15 heat flow experiment. Although the drill had a design flaw that was modified for the later missions, it seems that Apollo 15 was also hampered by landing on far more solid ground.

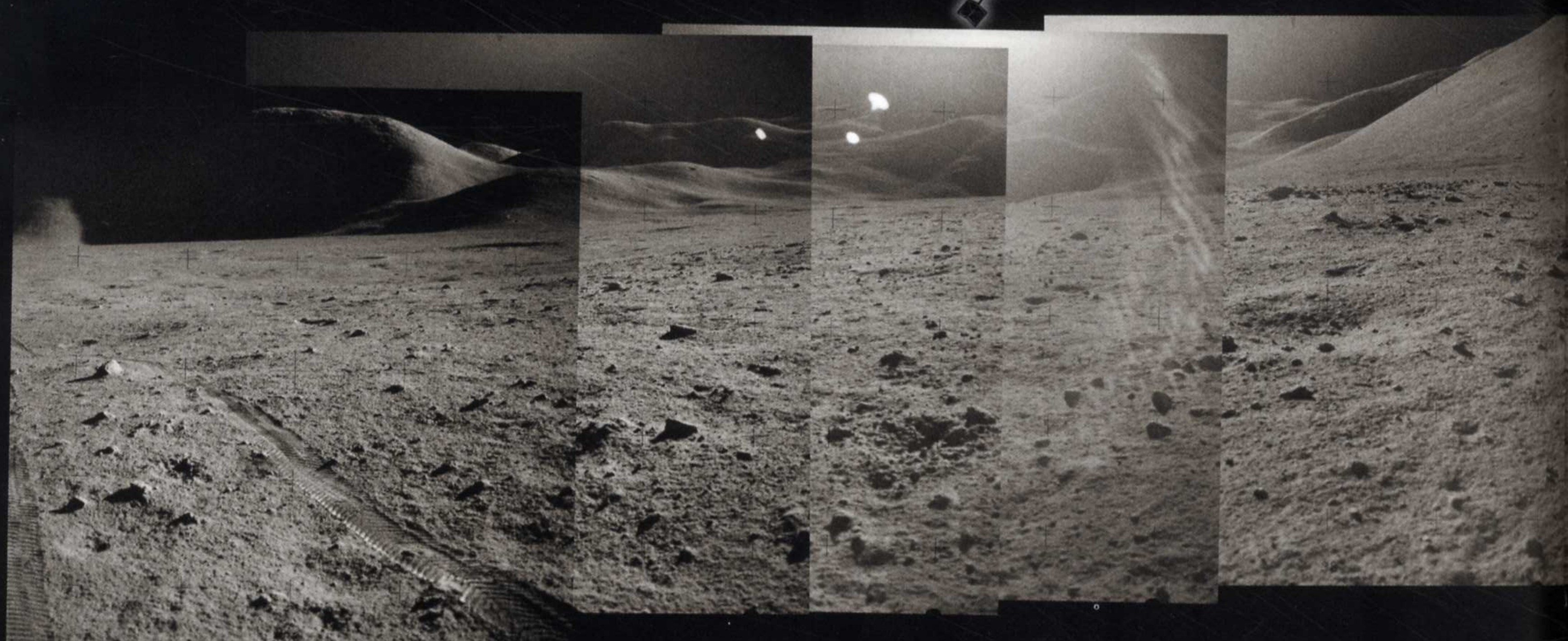
DIGGING A TRENCH
James Irwin's work digging a trench in the topsoil was easier than the drilling, but he still had to stop at a depth of 30cm (1ft).

"**Man must explore**, and this is exploration at its greatest."

Apollo 15 Commander David Scott, on Hadley Rille



70MM HASSELBLAD CAMERA
Specially modified Hasselblad electric cameras were carried on the chest packs of all the Apollo astronauts. The familiar + marks allowed measurements of distance to be made from the photographs.



Apollo 15

Back on firm ground after the success of Apollo 14, the next Apollo mission was a major advance, as an improved CSM, a longer stay on the Moon, and the addition of a lunar rover yielded great results.

Apollo 15 was the first of what were known as the J missions – the ultimate development of Apollo as it was initially planned. For these missions, modifications to the CSM (in this case *Endeavour*) included the addition of a palette of scientific instruments mounted on the Moon-facing side of the hull. These would turn the orbiting module into a powerful science satellite in its own right and give the CSM pilot an expanded role in the mission. The LM, meanwhile, now carried the Lunar Roving Vehicle (LRV) – a Moon car developed by Boeing, which was folded and stored on the side of the module during descent. This massively increased the range over which the astronauts could travel, but improvements to life-support systems also had a role to play, as they allowed a much longer stay on the lunar surface.

Apollo 15's crew was led by Neil Armstrong's Gemini 8 partner David Scott, with James Irwin as LM Pilot and Alfred Worden in the CSM. Apollo 15 blasted off on 26 July 1971 and arrived in lunar orbit without any major problems.

Climbing lunar mountains

The Lunar Module *Falcon* touched down near a long, winding valley known as Hadley Rille on 30 July, and during almost three days on the Moon, Scott and Irwin undertook three separate moonwalks. The first of these tested the LRV on a trip to the base of Mons Hadley Delta, a mountain in the Lunar Apennine range some 4km (2½ miles) away. The rover performed well, although Scott had some difficulty getting used to its rear-wheel steering. Travelling at an average of 10kph (6mph), they needed to test the brakes on several occasions when they unexpectedly found themselves on the edge of a crater.

During this expedition, they made two long stops to explore geology around Elbow Crater and at the base of the mountain itself. In preparation for their mission, these astronauts had undergone far more extensive geology field training than their predecessors (including simulated expeditions in the New Mexico desert), and the extra work paid off as the later Apollos generated huge amounts of data that would ultimately allow geologists back on Earth to piece together the Moon's history.

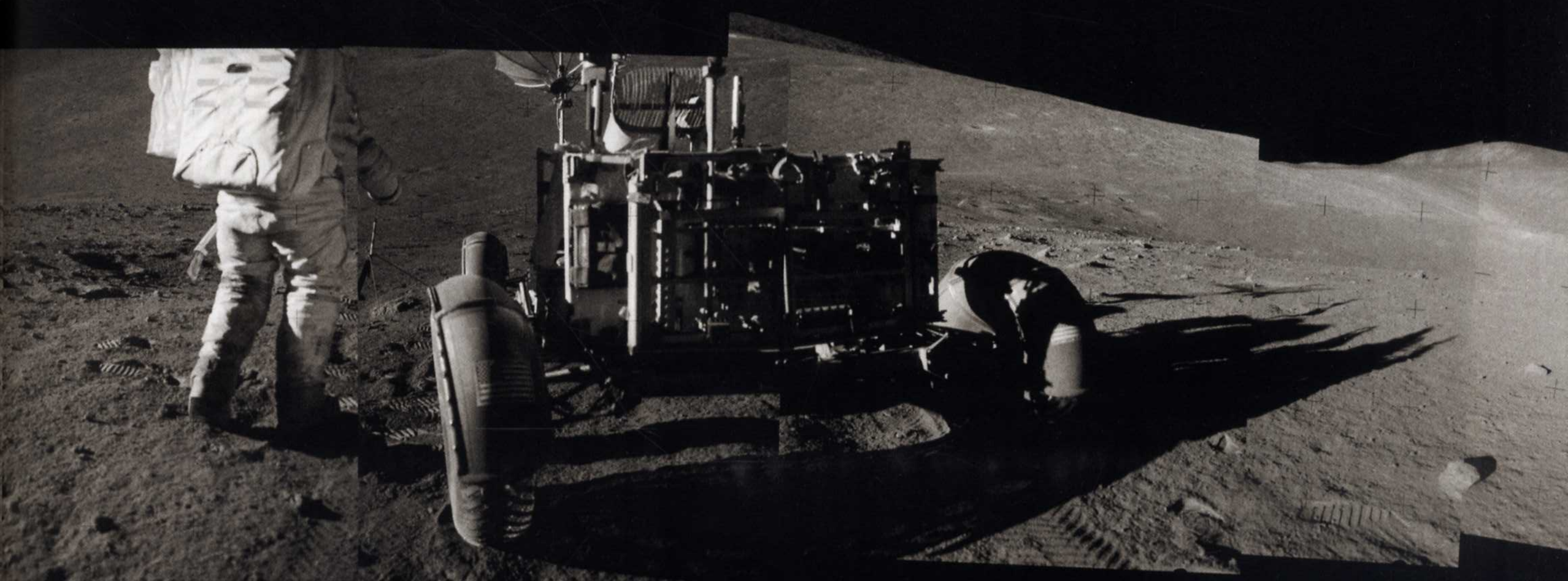
On the second day, the astronauts returned to the same area, but this time they climbed the mountain itself, collecting samples including one that was later nicknamed "the genesis rock" after studies back on Earth revealed that it was more than four billion years old – almost as old as the Moon itself. Back at the LM, the astronauts had also been at work setting up the ALSEP package and conducting other experiments. Drilling into the lunar rocks to collect samples proved far more difficult than expected, and the final LRV expedition had to be shortened – though it still took the astronauts to the edge of Hadley Rille itself.

After their return to the CSM on 2 August, the astronauts spent a further two days in lunar orbit, during which time they continued scientific work and deployed a small satellite into lunar orbit.

BIOGRAPHY

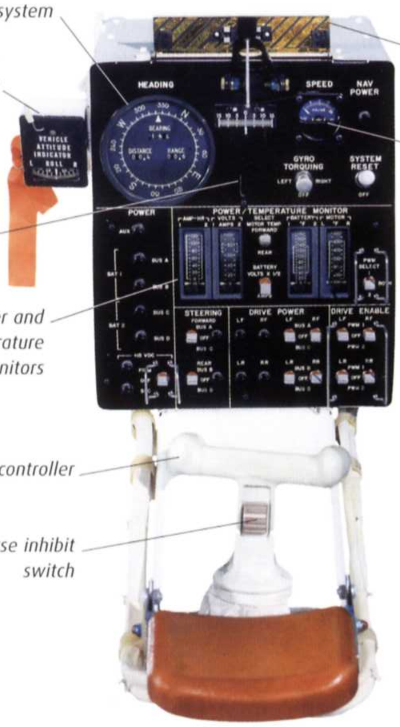
DAVID SCOTT

Texan David Randolph Scott (b.1932) was educated at West Point before enlisting in the US Air Force. After a tour of duty in Europe, he returned to study in America before joining NASA in 1963. His first flight on Gemini 8 (see p.108), was followed by the role of CM Pilot on Apollo 9. After Apollo 15, he took part in preparations for the Apollo–Soyuz Test Project (see p.174). He left NASA in 1975.

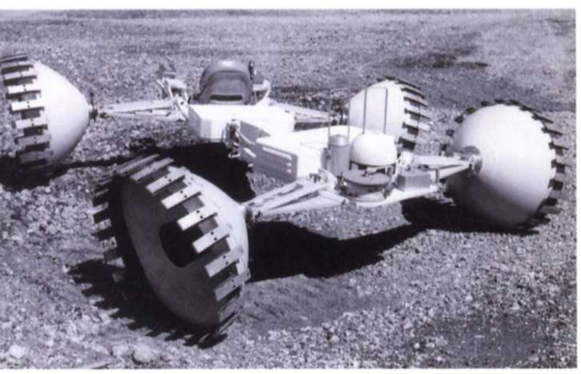


FIRST WHEELS ON THE MOON

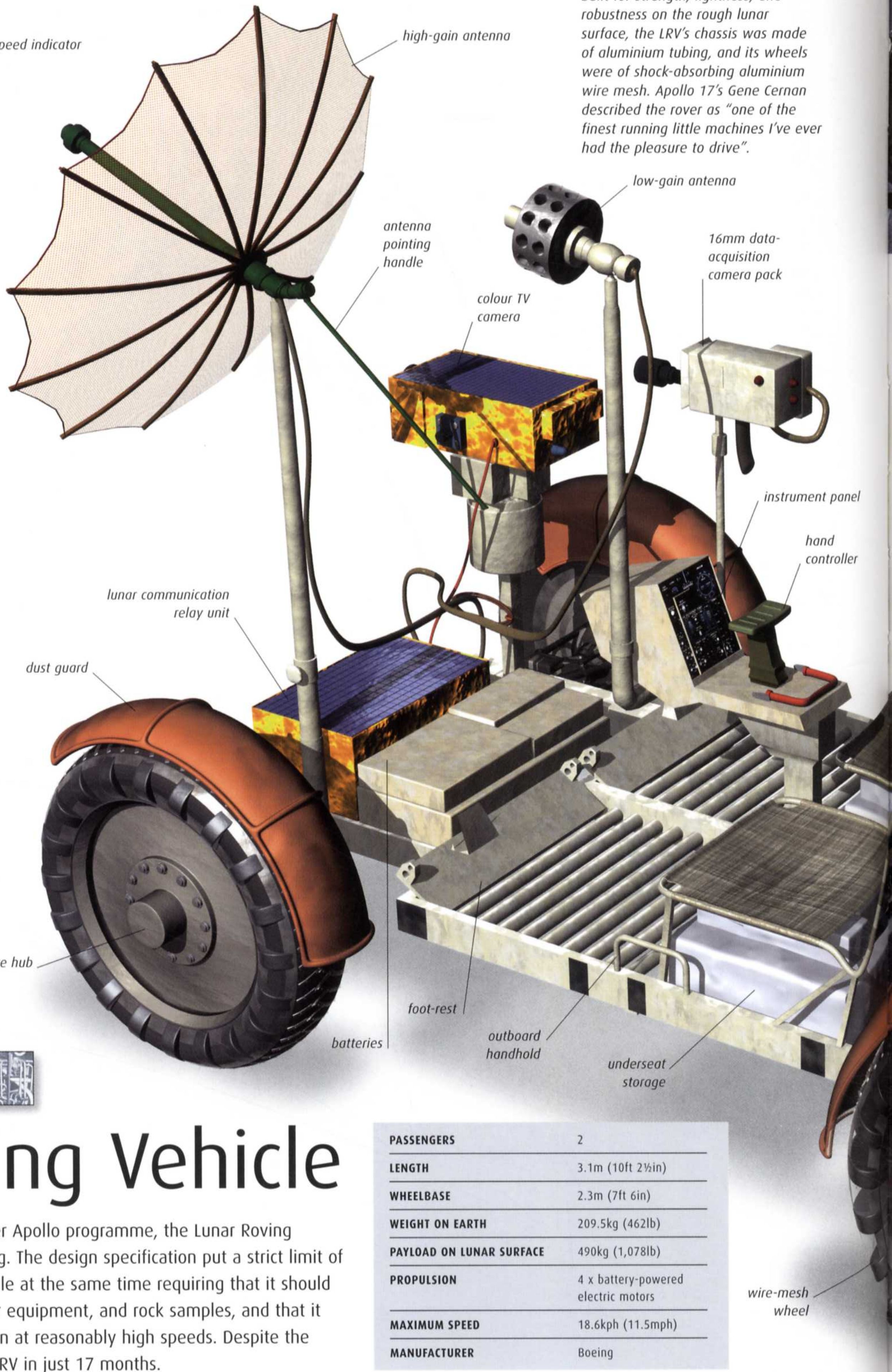
The LRV is seen here shortly after its first deployment onto the Moon. The tyres were actually made of woven wire mesh with chevron-shaped treads riveted on – making them far more effective shock absorbers.



CONTROL CONSOLE
The LRV was driven with a simple hand controller – pushing forwards increased speed, while turning steered the wheels. Reverse gear was blocked unless a switch on the controller's upright section was pressed.



MOBILITY TEST ARTICLE
Marshall Space Flight Center at Huntsville led the development of the LRV, building various "test articles" that led to the finished vehicle. Independent motors and steering for each wheel were a vital element of the LRV's final design.



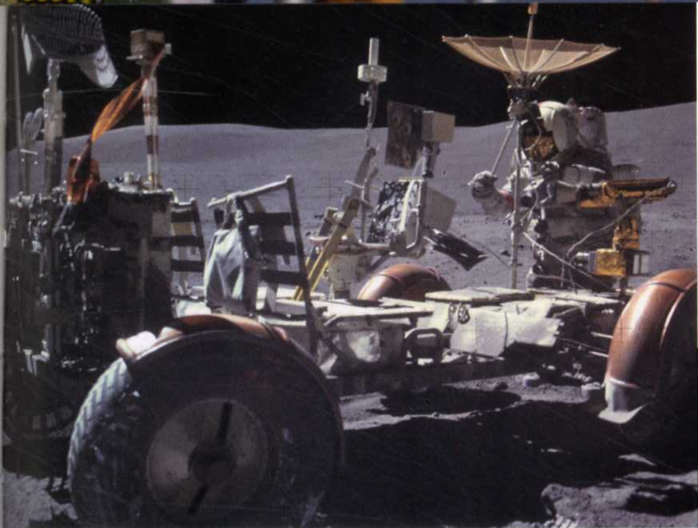
LUNAR ROVING VEHICLE
Built for strength, lightness, and robustness on the rough lunar surface, the LRV's chassis was made of aluminium tubing, and its wheels were of shock-absorbing aluminium wire mesh. Apollo 17's Gene Cernan described the rover as "one of the finest running little machines I've ever had the pleasure to drive".

TECHNOLOGY
A CAR FOR THE MOON

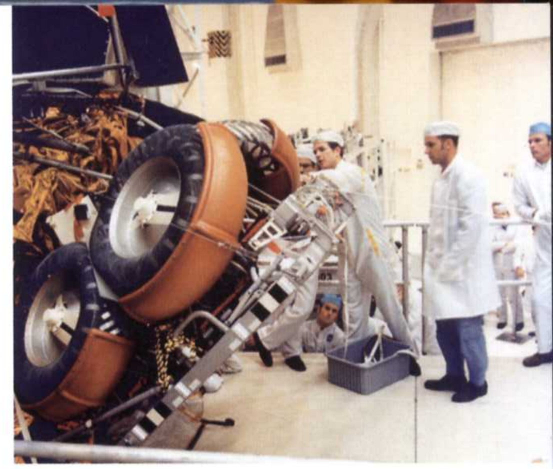
Lunar Roving Vehicle

Developed for the J-class missions of the later Apollo programme, the Lunar Roving Vehicle (or LRV) was built for NASA by Boeing. The design specification put a strict limit of 208kg (457.5lb) on the vehicle's weight, while at the same time requiring that it should support a heavy load of two astronauts, their equipment, and rock samples, and that it should be capable of many hours of operation at reasonably high speeds. Despite the demanding brief, Boeing delivered the first LRV in just 17 months.

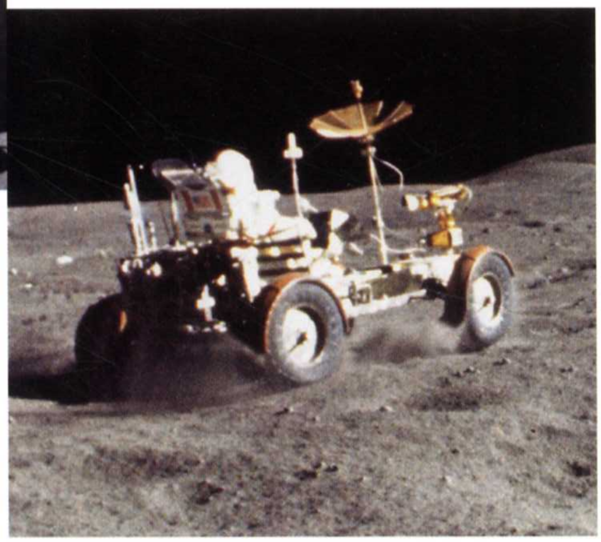
PASSENGERS	2
LENGTH	3.1m (10ft 2½in)
WHEELBASE	2.3m (7ft 6in)
WEIGHT ON EARTH	209.5kg (462lb)
PAYLOAD ON LUNAR SURFACE	490kg (1,078lb)
PROPULSION	4 x battery-powered electric motors
MAXIMUM SPEED	18.6kph (11.5mph)
MANUFACTURER	Boeing



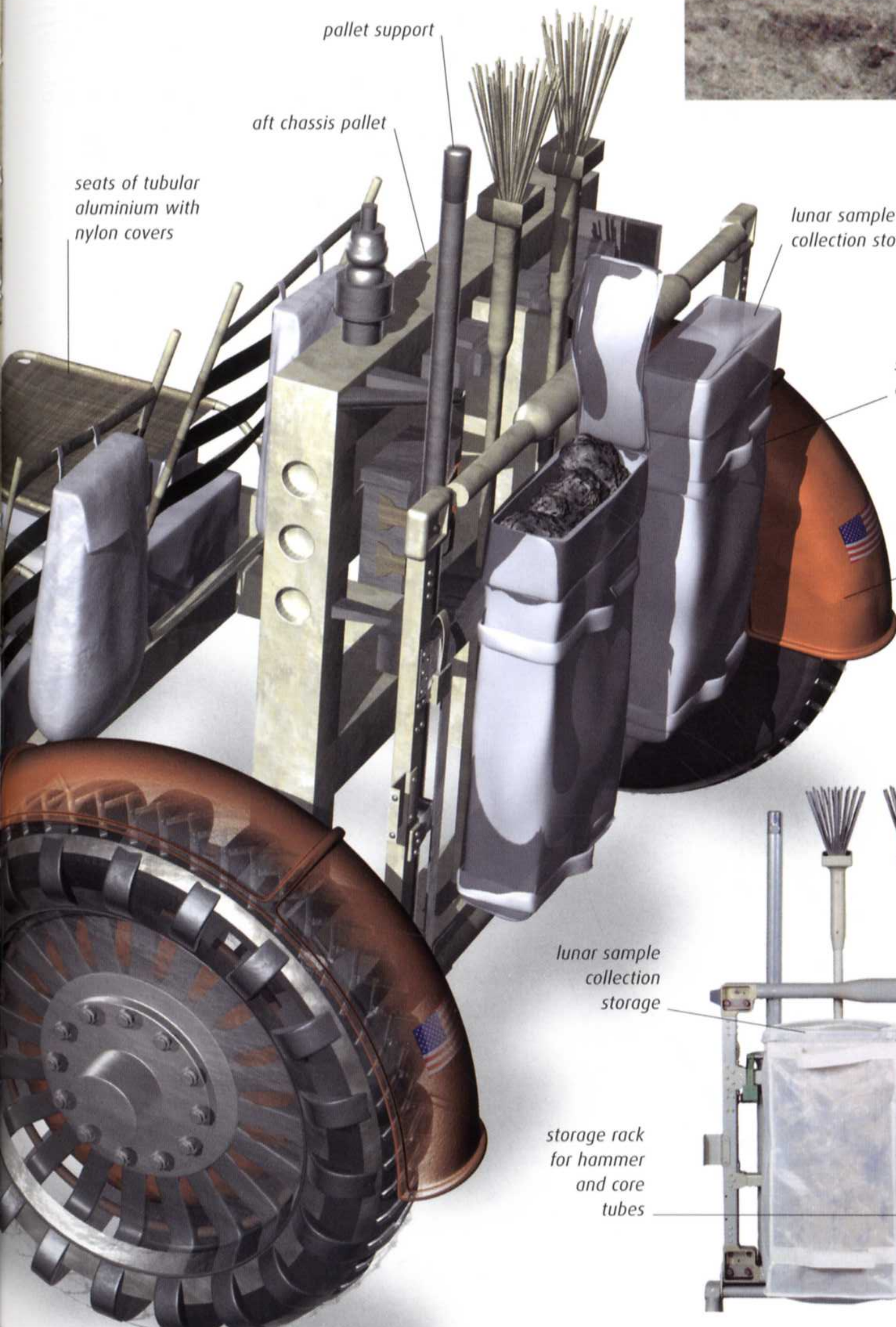
LINK TO EARTH
John Young, Commander of Apollo 16, adjusts the high-gain antenna on the LRV. The rover's communications system sent back a range of telemetry data while it was moving and could transmit live television pictures back to Earth when the vehicle was stationary.



KIT CAR
Apollo 15 Commander David Scott admires the deployment mechanism that would lower the LRV from the side of his Falcon *Lunar Module for the first drive on the surface of the Moon.*

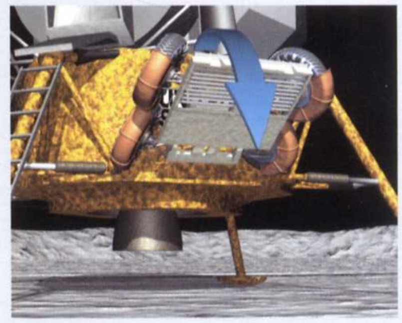


LUNAR GRAND PRIX
During the Apollo 16 mission, the astronauts put the LRV through a thorough performance test, pushing it to the limit and reaching a record speed of 18.6kph (11.5mph).

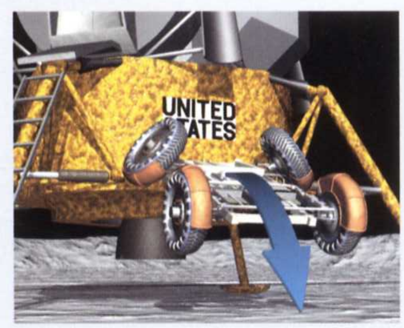


LUNAR HAND TOOL CARRIER
The rear upright section of the LRV was a rack holding various geology tools and sample bags for use on the rover's daily expeditions across the surface.

DEPLOYING THE ROVER
The LRV was stowed for flight on the side of "Quad 1" of the Lunar Module. It was designed to fold inwards for storage, leaving only the underside of the chassis exposed to damage during landing. It was lowered to the ground on a pulley system.

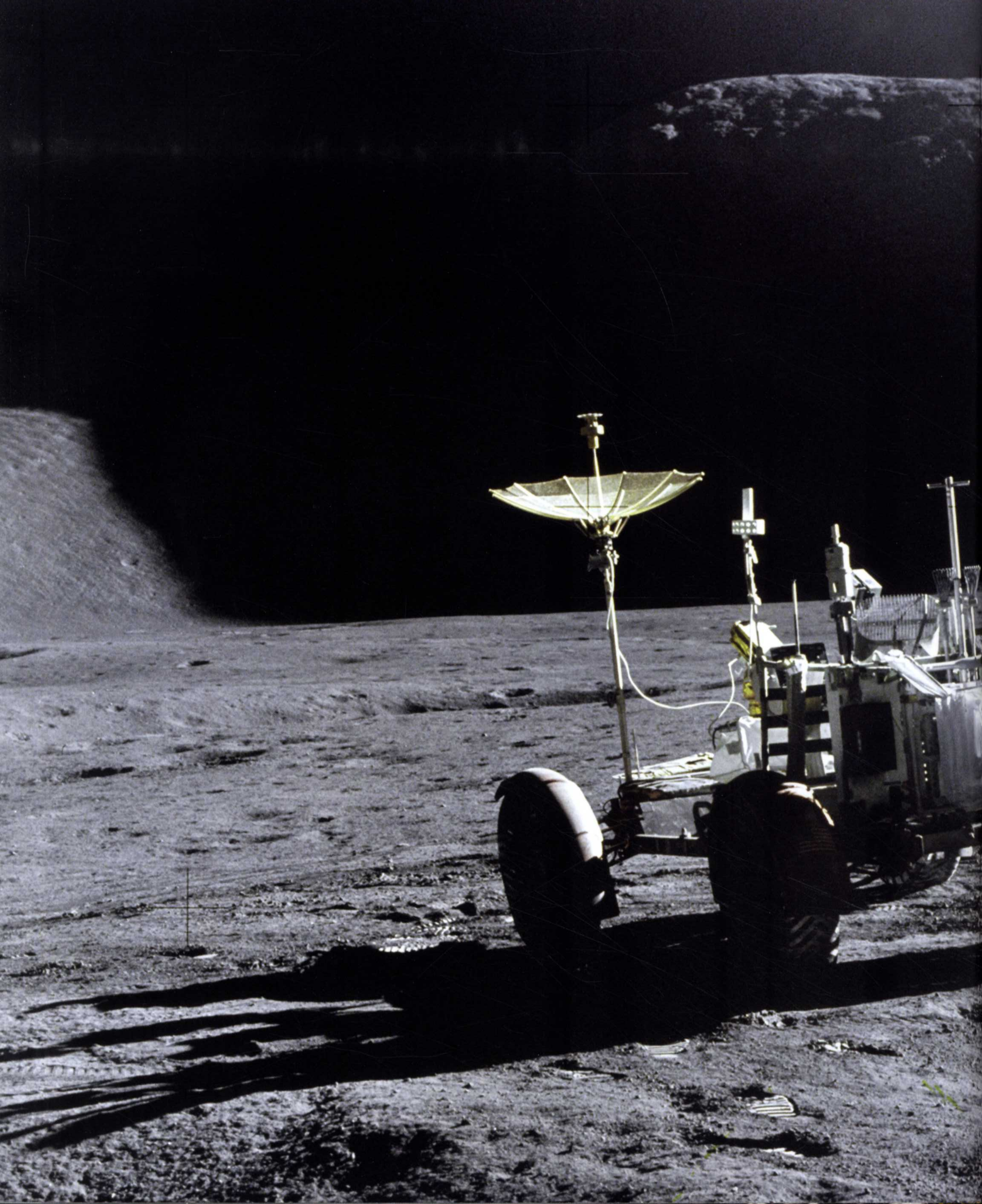


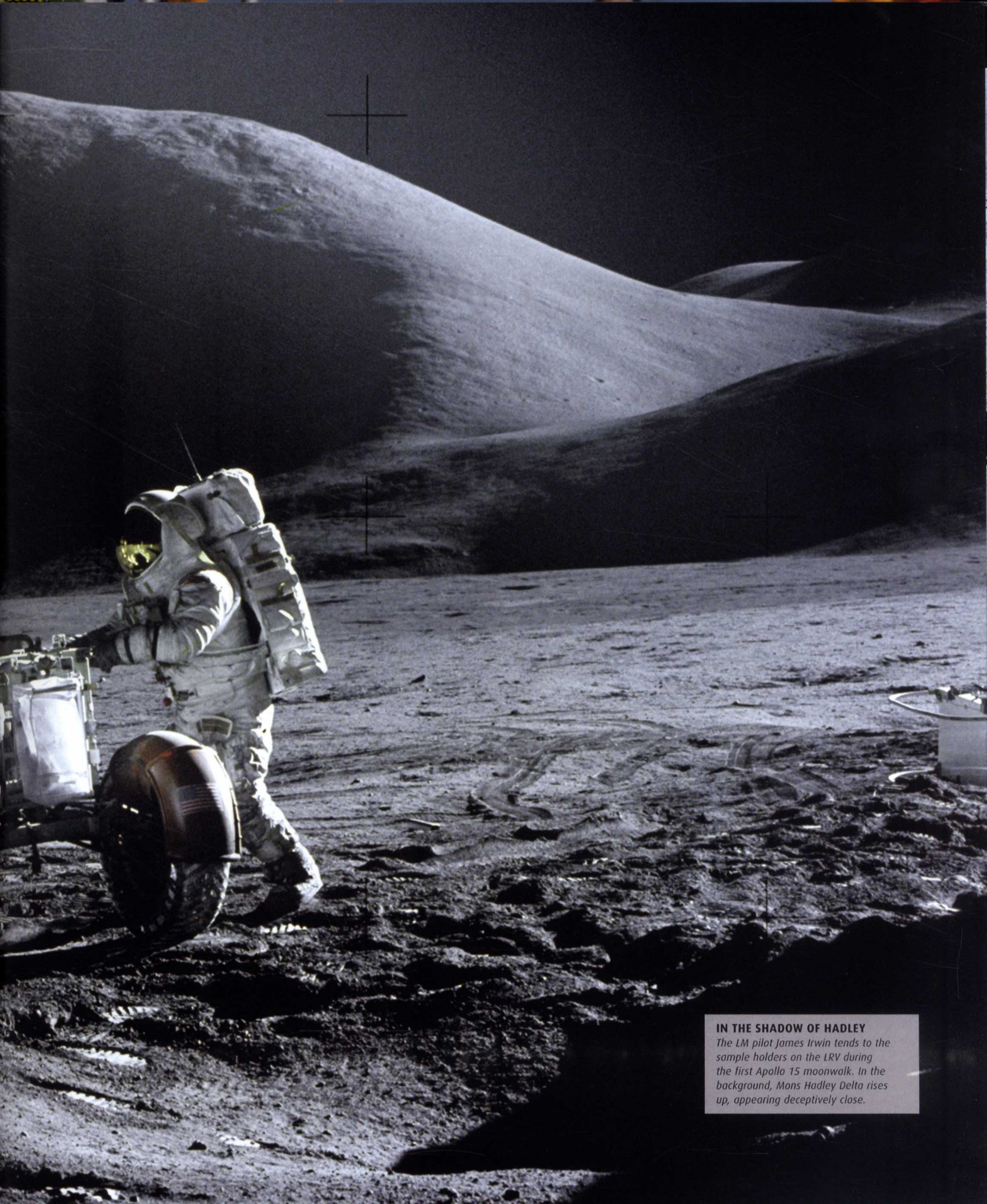
FLIP OPEN
From the porch, one astronaut released the LRV from its stowed position. His colleague then lowered it on pulleys.



FOLD DOWN
As the rover opened, the rear wheels rotated and locked into place automatically.

ROLL OFF
With the rear wheels down, the front wheels were unfolded, and the front of the LRV was lowered to the ground.





IN THE SHADOW OF HADLEY
The LM pilot James Irwin tends to the sample holders on the LRV during the first Apollo 15 moonwalk. In the background, Mons Hadley Delta rises up, appearing deceptively close.

16 April 1972
Apollo 16 blasts off from Kennedy Space Center.

19 April 1972
The spacecraft arrives in lunar orbit.

20 April 1972
A fault in the CSM almost forces the mission to abort during the Lunar Module's final descent to the Moon. However, the CM *Casper* is eventually allowed to continue, making the first landing in the lunar highlands.

21 April 1972
John Young and Charles Duke make the first of three highly successful moonwalks, retrieving the huge rock known as "Big Muley".

24 April 1972
After their third moonwalk, the astronauts return to the LM *Orion*. A few hours later, an engine burn puts the CSM on its return path to Earth – one day ahead of schedule for safety reasons after the problem with the CSM engines.

27 April 1972
Apollo 16 splashes down in the Pacific Ocean near Christmas Island.

Apollo 16

The second of the advanced Apollo-J missions targeted the Descartes region of the Moon and once again produced impressive scientific results.

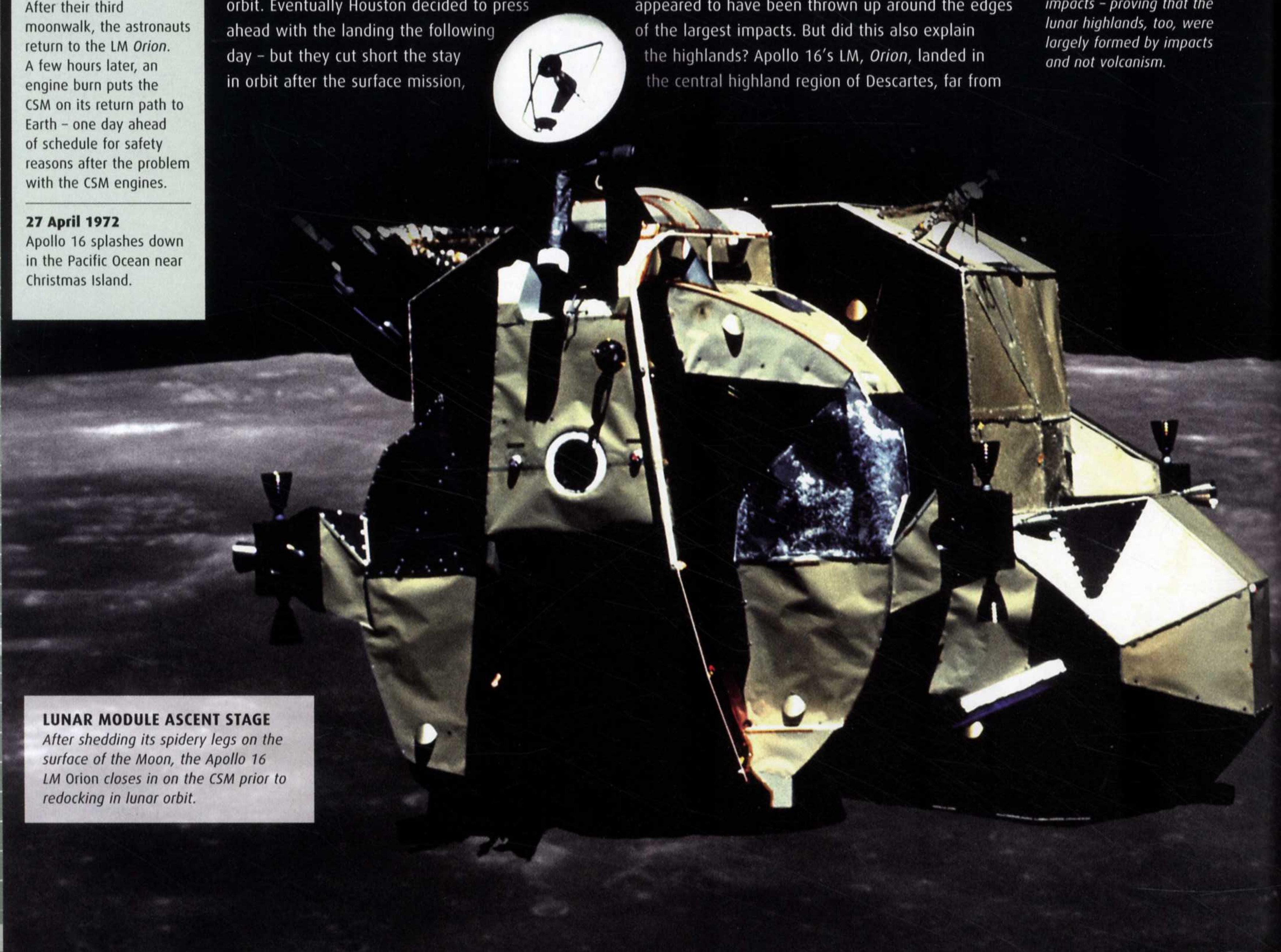
AT OUTHOUSE ROCK
Charles Duke indicates the location from which a sample was collected during the third moonwalk. Nearly all the rocks found in Descartes were breccias – rocks mixed up and re-formed by meteorite impacts – proving that the lunar highlands, too, were largely formed by impacts and not volcanism.

The crew for the fifth lunar landing was led by experienced Apollo and Gemini astronaut John Young, with two unflown astronauts, Thomas K. (Ken) Mattingly and Charles Duke, as Command Module Pilot and Lunar Module Pilot respectively. Young, Duke, and Jack Swigert had originally been the backup crew for Apollo 13, with Mattingly scheduled as CMP for that mission. After Mattingly was exposed to German measles, Swigert and Mattingly had switched places in the crew roster.

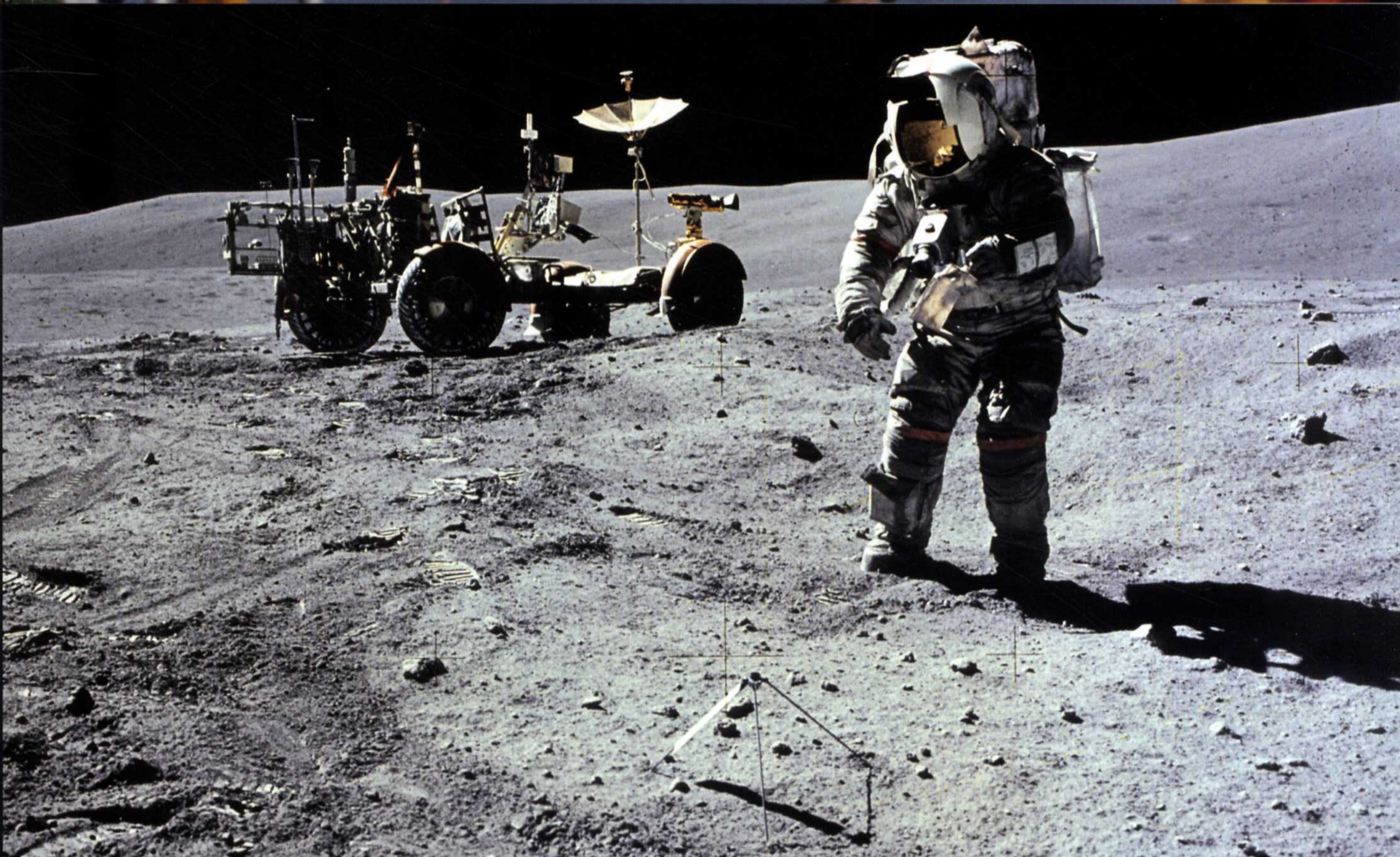
After an uneventful trip to the Moon, the mission was almost aborted during the CM's final descent, on 20 April. A fault developed in one of the thrusters on the CM, *Casper*, hampering its manoeuvres in lunar orbit. Eventually Houston decided to press ahead with the landing the following day – but they cut short the stay in orbit after the surface mission, and Apollo 16 returned to Earth a day early.

Highland fling

The Moon's surface is divided into two distinct types of terrain: low-lying, dark, flat seas or *maria*; and bright, heavily cratered highlands. The previous Apollo landings had all been in or around the lunar seas and had confirmed that they were vast plains of solidified volcanic lava filling huge ancient impact basins. Mountain chains such as the Lunar Apennines, investigated by Apollo 15, appeared to have been thrown up around the edges of the largest impacts. But did this also explain the highlands? Apollo 16's LM, *Orion*, landed in the central highland region of Descartes, far from



LUNAR MODULE ASCENT STAGE
After shedding its spidery legs on the surface of the Moon, the Apollo 16 LM Orion closes in on the CSM prior to redocking in lunar orbit.



LAST STOP
John Young stands in front of the LRV at the final stop on the astronauts' third moonwalk. The three-legged object in the foreground is part of a gnomon, a device for recording the size and colour of rock samples.

any seas, where some geologists thought volcanic activity, not impacts, might have produced the mountainous plateau.

Out and about

The astronauts carried out moonwalks on three successive days. They spent more than 20 hours outside the LM and drove some 26.7km (16½ miles), taking the LRV to a top speed of 18kph (11mph). The terrain was heavily cratered and scattered with large boulders – among the samples the astronauts found was the largest lunar rock ever collected, an 11.7kg (25lb) monster nicknamed "Big Muley" after Bill Muehlberger, the mission's principal geologist.

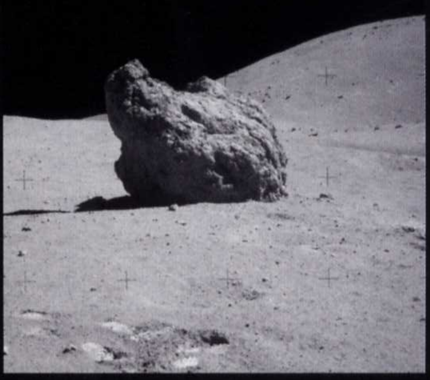
Young and Duke also experienced some unusual problems. On the first EVA they drove directly away from the Sun and, with no shadows to help them, had trouble spotting obstacles against the glare of reflected sunlight. The orange-juice pouches that each astronaut carried inside his helmet to guard against dehydration were another source of irratation, as they kept leaking or clogging up.

Casper and *Orion* were reunited in the early hours of 24 April, and once astronauts and rock samples had transferred to the CSM, *Orion* was cast adrift, though a fault with the planned de-orbit burn meant that it did not impact immediately as intended but eventually crashed to the Moon about a year later. A small satellite was deployed before the CSM left orbit, carrying experiments to study any particles in lunar orbit, and the Moon's feeble magnetic field. During the return flight, Mattingly made a spacewalk, venturing outside the CSM to retrieve a film canister and experimental equipment.

BIOGRAPHY

CHARLES DUKE

After studying at both the US Naval Academy and the Massachusetts Institute of Technology, North Carolina-born Charles M. Duke (b.1935) joined the US Air Force, serving in Germany before returning to America to train as a test pilot. Graduating from the Aerospace Research Pilot School in 1965, he stayed on as an instructor before joining NASA's fifth astronaut training group in 1966. He was Capcom, the "voice of Mission Control", during Apollo 11 and the backup LM pilot for both Apollos 13 and 17. He retired from NASA in 1975 to go into business.



SHADOW ROCK
During the course of their third moonwalk, Young and Duke came across this distinctive tilted rock. Samples taken from underneath its base produced soil that had not seen sunlight in perhaps a billion years.

1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

Apollo 17

The final Apollo mission was humankind's temporary farewell to the Moon. Even at the end of the programme, it was able to achieve another first – putting a qualified geologist on the lunar surface.

7 December 1972
Apollo 17 lifts off over two hours late after a countdown problem.

10 December 1972
The spacecraft arrives in lunar orbit, just ahead of its own S-IVB rocket stage, which is then deliberately crashed into the Moon. The impact is detected by seismometers set up by previous Apollo missions.

11 December 1972
The LM Challenger lands in the Taurus-Littrow valley. Later, Cernan and Schmitt make the first of three lengthy moonwalks.

14 December 1972
At the end of the third surface moonwalk, Cernan becomes the last man to step on the Moon in the 20th century.

16 December 1972
The CSM *America* heads for home.

19 December 1972
Apollo 17 splashes down in the Pacific Ocean.

21 December 1972
A reception at Houston marks the end of the Apollo programme.

John F. Kennedy's ambition to reach the Moon – and just as importantly to beat the Soviet Union in the Space Race – had hung over his successors ever since the President's tragic assassination in November 1963. Apollo was a matter of national prestige, and the public would not forgive any politician who allowed it to slip from his priorities.

But with the race won, the question was – what next? By now, the United States was bogged down in the divisive and expensive Vietnam War, and the Apollo-era NASA budget was unsustainable in the long term. In fact, it was under pressure within months of *Eagle*'s landing, as first one and then two more of the original missions were axed, even though most of the hardware was ready for them.

While Apollo's sprint for the Moon ran roughshod over von Braun's 1950s plans for a stately march across the Solar System, its technology could still have given rise to a permanent lunar outpost, had the money and the will been there. But a more pragmatic administration felt that America's future in space lay closer to home. Apollo 17 would mark the end of lunar exploration for the foreseeable future.

Scientists in the valley

With fewer political constraints and no need to lay a basis for future colonization, the Apollo J missions could be governed almost entirely by scientific objectives, and so geologist Harrison "Jack" Schmitt took his place as Lunar Module Pilot on Apollo 17. Alongside him was Mission Commander Gene Cernan, and Command Module Pilot Ronald Evans.

After a spectacular night launch on 7 December 1972, the LM *Challenger* and the CSM *America* separated in orbit on 11 December, and Cernan and Schmitt touched down on the Moon shortly afterwards. This time the target was the Taurus-Littrow area, a flat-bottomed valley ringed by mountains, on the edge of the Sea of Serenity. The area seems to be one where lavas from the maria partially flooded a pre-existing valley.

Following the pattern of previous missions, there were three major moonwalks. Once again the focus was on collecting rock samples with the LRV, but the astronauts also deployed an unrivalled number of complex experiments as part of their ALSEP package. As on Apollo 15, several of these experiments involved drilling probes into the rock, and there were also core samples to be collected, but this time drilling went to plan and did not cause any delays. Meanwhile Evans conducted his own valuable experiments and observations from the orbiting CSM.

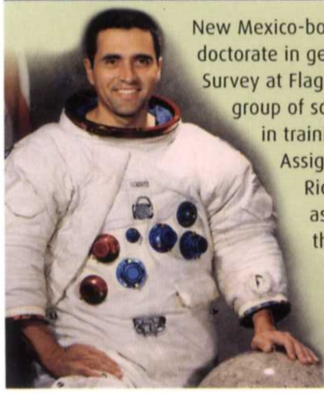
The valley was littered with boulders that seemed to have rolled down from the mountains around it, and these offered a valuable chance to study lunar bedrock that had not been altered by meteorite impacts. During their sampling expeditions, Cernan and Schmitt came across a bizarre patch of distinctly orange soil, which provoked a heated debate about its origins. It turned out to be a patch of naturally occurring glass (produced by a volcano) that had been uncovered during the formation of the nearby Shorty Crater. The astronauts also conducted a number of studies of the region's gravitational field – earlier probes and manned missions had already discovered regions of noticeably more powerful gravity, called mascons, apparently corresponding to denser areas of the lunar crust.

Last men on the Moon

The Apollo astronauts' final moments on the Moon included a small ceremony. They unveiled a plaque on the LM's landing strut to commemorate their visit and then packed away their samples and prepared for the return to Earth. Cernan was last aboard the LM, saluting the Stars and Stripes before declaring "... as we leave the Moon at Taurus-Littrow, we leave as we came and, God willing, as we shall return, with peace and hope for all mankind."

BIOGRAPHY

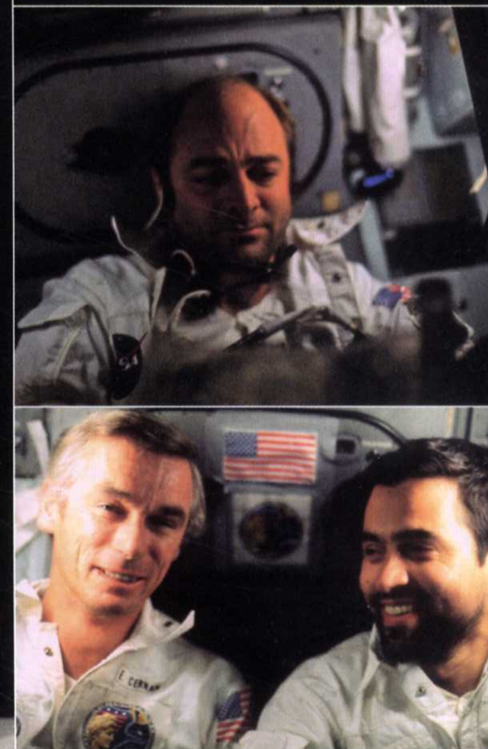
HARRISON SCHMITT



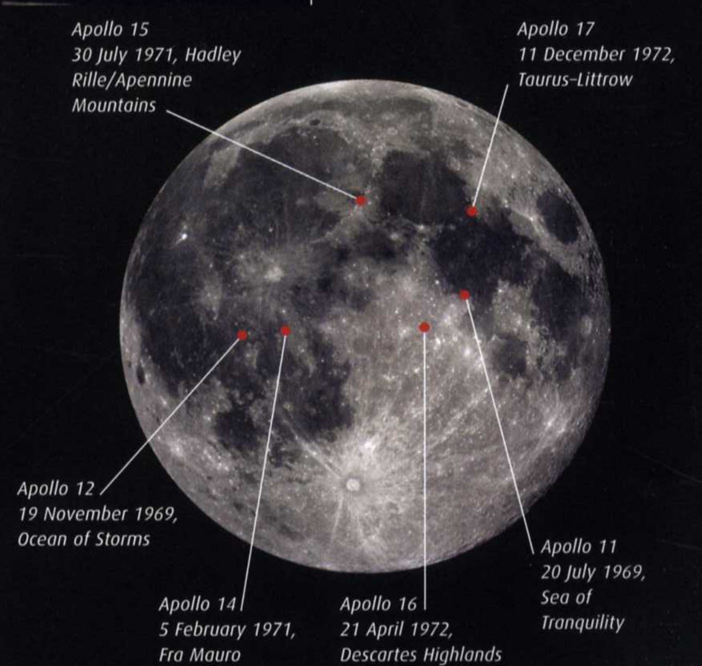
New Mexico-born Harrison Hagan "Jack" Schmitt (b.1935) gained a doctorate in geology from Harvard before joining the US Geological Survey at Flagstaff, Arizona. After his selection to NASA's first group of scientist-astronauts in 1965, he was closely involved in training the Apollo astronauts for geological fieldwork. Assigned to the backup crew of Apollo 15 alongside Richard Gordon and Vance Brand, he would have flown as LM pilot aboard Apollo 18, but the cancellation of that mission led to his replacing Joe Engle on Apollo 17. He retired from NASA in 1975 to enter politics and later business, and currently (2007) chairs the NASA Advisory Council, a group that advises the NASA Administrator.

"... America's challenge of today has forged **man's destiny of tomorrow**."

Gene Cernan, last Apollo astronaut to step on the Moon



GOODBYE TO THE MOON
A tired but elated Ron Evans (top), Gene Cernan, and Jack Schmitt (bottom left and right) relax as they return to Earth at the end of their three-week=long mission – the last in the historic Apollo programme.



APOLLO LANDING SITES
Apollo astronauts studied many of the major terrain types on the lunar near side, including lunar seas, mountain chains, lunar highlands, and the "ejecta blankets" around major craters.

Apollo crews 1967 – 1972

After the tragedy of Apollo 1, Saturn rockets took men into space 11 times during the US lunar programme. The publicity photos reproduced here chronicle an era that cemented the image of the astronaut as hero.

APOLLO 1
Commander (left) *Virgil "Gus" Grissom (1926–1967)*
CM Pilot (centre) *Ed White (1930–1967)*
LM Pilot (right) *Roger Chaffee (1935–1967)*
Mission *Never flew after catastrophic launch-pad fire*

APOLLO 7
LM Pilot *Walter Cunningham (b.1932)*
Commander *Wally Schirra (b.1923)*
CM Pilot *Donn Eisele (1930–1987)*
Mission *11–22 October 1968*

APOLLO 8
CM Pilot *Jim Lovell (b.1928)*
LM Pilot *William Anders (b.1933)*
Commander *Frank Borman (b.1928)*
Mission *21–27 December 1968*

APOLLO 12
Commander *Charles "Pete" Conrad (1930–1999)*
CM Pilot *Richard Gordon (b.1929)*
LM Pilot *Al Bean (b.1932)*
Mission *14–24 November 1969*

APOLLO 13
CM Pilot *John L. "Jack" Swigert (1931–1982)*
Commander *Jim Lovell (b.1928)*
LM Pilot *Fred Haise (b.1933)*
Mission *11–17 April 1970*

APOLLO 14
CM Pilot *Stuart Roosa (1933–1994)*
Commander *Alan Shepard (1923–1998)*
LM Pilot *Edgar Mitchell (b.1930)*
Mission *31 January – 9 February 1971*

APOLLO 9
Commander *James McDivitt (b.1929)*
CM Pilot *David Scott (b.1932)*
LM Pilot *Russell Schweickart (b.1935)*
Mission *3–13 March 1969*

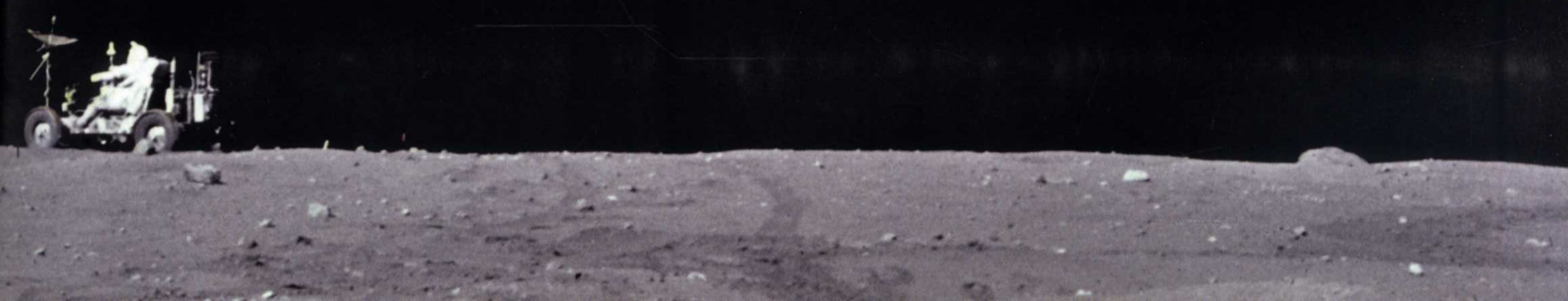
APOLLO 10
LM Pilot *Gene Cernan (b.1934)*
CM Pilot *John Young (b.1930)*
Commander *Thomas Stafford (b.1930)*
Mission *18–26 May 1969*

APOLLO 11
Commander *Neil Armstrong (b.1930)*
CM Pilot *Michael Collins (b.1930)*
LM Pilot *Buzz Aldrin (b.1930)*
Mission *16–24 July 1969*

APOLLO 15
Commander *David Scott (b.1932)*
CM Pilot *Alfred Worden (b.1932)*
LM Pilot *James Irwin (1930–1991)*
Mission *26 July – 7 August 1971*

APOLLO 16
CM Pilot *Thomas K. "Ken" Mattingly (b.1936)*
Commander *John Young (b.1930)*
LM Pilot *Charles Duke (b.1935)*
Mission *16–27 April 1972*

APOLLO 17
LM Pilot *Harrison "Jack" Schmitt (b.1935)*
Commander *Gene Cernan (b.1934)*
CM Pilot *Ronald Evans (1933–1990)*
Mission *7–19 December 1972*



JUNE 1973: SKYLAB OVER EARTH
NASA's space station shows the scars of its traumatic launch and hasty repairs – a lopsided arrangement of solar panels and an improvised foil sunshade deployed by the Skylab 2 mission.

AFTER APOLLO

WITH THE RACE FOR THE MOON WON AND LOST, what next? After the overthrow of Khrushchev and the rise of a monolithic regime not given to "spectaculars", the Soviet Union soon decided that the practical exploitation of near-Earth space, for both civilian and military purposes, was to take priority. And if their early exit from the race to the Moon allowed them to tell the world they had never been interested in the first place, then so much the better. This, then, was to be a brave new era of Soviet cosmonautics – the era of the space stations.

NASA faced a different challenge. The very nature of the Apollo programme dictated that it would be short-lived, and development of America's next spacecraft, the much-hyped, much-delayed Space Shuttle, was only just beginning. However, there was still spare hardware left from three cancelled Apollos, and this would allow NASA to create a space station of its own and ultimately link up with the Soviets in space in a historic gesture that marked the definitive end of the Space Race.

14 May 1973
The launch of the unmanned Skylab space station atop a Saturn V rocket goes badly wrong and leaves the station crippled in orbit.

25 May 1973
The Skylab 2 launch carries the first crew to the station, with a complex repair mission to carry out before their scientific work can begin.

22 June 1973
Skylab 2 splashes down after 28 days in orbit – a new space endurance record for the crew.

28 July 1973
Skylab 3 begins a 59-day mission that sets another endurance record.

16 November 1973
Skylab 4 is launched on the third and final mission to the station.

8 February 1974
The Skylab 4 crew return to Earth after a record 84 days in orbit.

11 July 1979
The Skylab space station is destroyed re-entering the Earth's atmosphere. Parts land in Australia.

Laboratory in the sky

America's first space station, Skylab, was lofted into orbit in May 1973 in the final spectacular launch of a Saturn V rocket. Over the following year, three crews completed increasingly lengthy missions onboard.

Skylab 1, the space station's unmanned launch mission, almost ended in disaster. A shield designed to protect the station's walls from meteoroid impacts and the direct heat of the Sun deployed too early, and was ripped away by the supersonic air, carrying one of the two main solar panels with it. A loose metal strip then snagged across the remaining panel, preventing it from unfolding at all. By the time Skylab had reached orbit, it was already crippled – almost powerless and overheating badly. Only the smaller solar panels atop the Apollo Telescope Mount unfolded correctly.

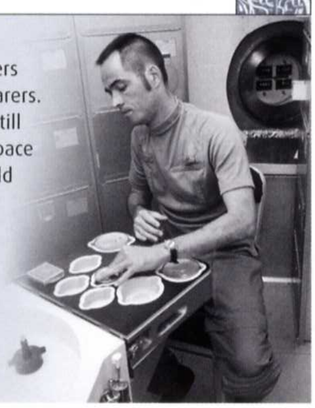
Skylab on-line

The launch of Skylab 2, carrying the first crew of Pete Conrad, Joe Kerwin, and Paul Weitz, should have taken place the following day but was postponed while the engineers came up with a repair plan. Finally the trio rocketed skyward atop a Saturn IB 10 days late. After an unsuccessful attempt at untangling the remaining solar panel from onboard the Apollo CSM, they docked successfully and boarded the overheated station, pushing a hurriedly designed reflective parasol through a hatch and opening it up to provide some protection from the Sun. A complex spacewalk then finally released the snagged panel, providing the station with much-needed power and finally bringing it fully on-line.

With the station up and running, the astronauts were able to stay aboard for a total of 28 days, a new record for the longest stay in space. They continued to make repairs throughout the flight but also had time to carry out many experiments. These included observations and photography of the Earth and Sun, as well as medical experiments in which the astronauts themselves were guinea pigs, and five experiments suggested by high-school students back on Earth.

TECHNOLOGY

FOOD ADVANCES



The arrival of space stations increased the duration of missions from days to weeks and forced mission planners to reconsider the menus they were providing to spacefarers. Although much of the food carried aboard Skylab was still freeze-dried, the pastes and cubes supplied on early space missions were supplemented with frozen food that could be cooked in the station's galley area. Meals were prepared on metal trays that also acted as hotplates to warm the food. A magnetized upper surface held down the metal bowls and cutlery.

Science in orbit

Skylab 3, crewed by Al Bean, Jack Lousma, and Owen Garriott, returned to a station that had been empty for just over a month, in late July 1973. Aside from installing an improved sunshield and troubleshooting a problem with their own spacecraft's manoeuvring engines, the astronauts of this mission were able to concentrate on science. As well as studying their own condition during 59 days of weightlessness, they also recorded how a variety of smaller passengers coped, including mice, fruit flies, and spiders, as well as conducting a range of student experiments.

The last and longest of the Skylab missions saw Gerald Carr, Bill Pogue, and Edward Gibson spend 84 days in orbit. Although Skylab 4 involved a huge variety of experiments and observations – including studies of the giant Comet Kohoutek using the station's solar telescope – the crew spent much of the time in conflict with Ground Control, complaining that they were being worked too hard, while some mission controllers felt they weren't doing enough. Despite a highly successful mission, none of them was selected to fly into space again.

JETPACK TESTING
The large volume of Skylab allowed astronauts to test a rocket pack called the Automatically Stabilized Maneuvering Unit (ASMU). This was a prototype of the Manned Maneuvering Unit (MMU), later used on Space Shuttle missions *(see p.194)**.*

BIOGRAPHY

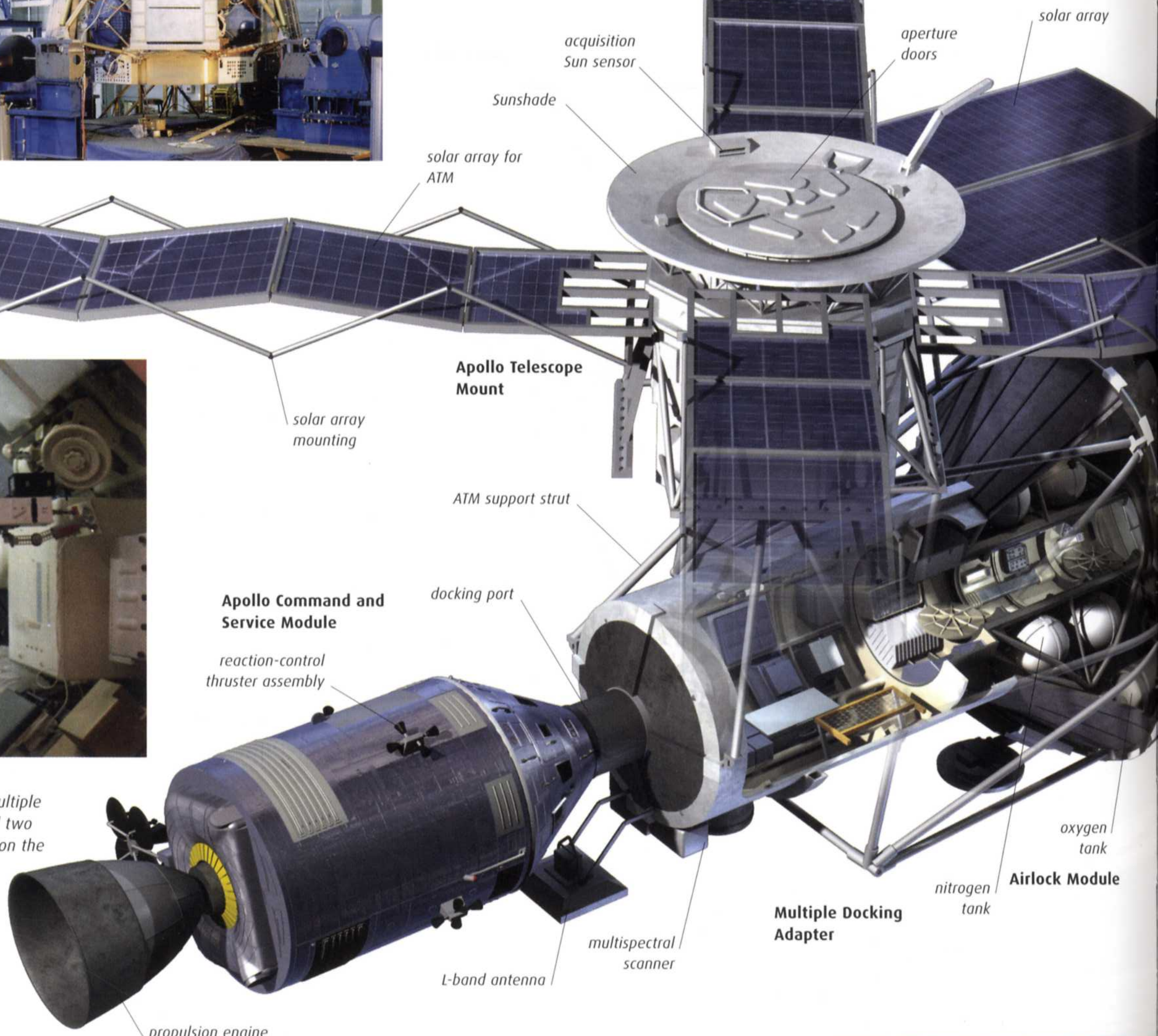
PETE CONRAD

Charles "Pete" Conrad (1930–99) was the third man to walk on the Moon, as commander of Apollo 12. Born in Pennsylvania, he studied aeronautics at Princeton before joining the US Navy and becoming a test pilot. He was selected for astronaut training in 1962 and first flew aboard Gemini 5 in 1965. A year later, he commanded Gemini 11. His first Apollo assignment was backup commander for the mission that became Apollo 9 – had it not been for the rearrangement of Apollos 8 and 9, he might well have been in line for the first manned landing on the Moon. After Skylab 2, Conrad quit both NASA and the Navy for a new career in business. He died following a motorcycle accident a month after his 69th birthday.

WORK AND PLAY ABOARD SKYLAB

(Left) Gerald Carr of Skylab 4 jokingly shows his strength by lifting up colleague Bill Pogue with one finger. (Above top) Personal hygiene was more important on longer missions – here Jack Lousma of Skylab 3 has a weightless shower. (Above centre) Al Bean operates an ultraviolet astronomical camera aboard Skylab 3. (Above bottom) Often the astronauts themselves were scientific guinea pigs – here, Skylab 2's Pete Conrad submits to the first dental examination in orbit, at the hands of colleague Joe Kerwin.

APOLLO TELESCOPE MOUNT
The Apollo Telescope Mount (ATM) was a large observatory originally planned for independent launch before being combined with Skylab. It is shown here during testing at Marshall Spaceflight Center.



MULTIPLE DOCKING ADAPTER
Located at one end of Skylab, the Multiple Docking Adaptor (MDA) incorporated two docking points for Apollo CSMs: one on the main axis of the station for normal docking operations; and the other to one side for emergency use. Here, Pete Conrad is rehearsing procedures in the Skylab mock-up in the Mission Simulation and Training Facility at Houston.

TECHNOLOGY

AMERICA'S FIRST SPACE STATION

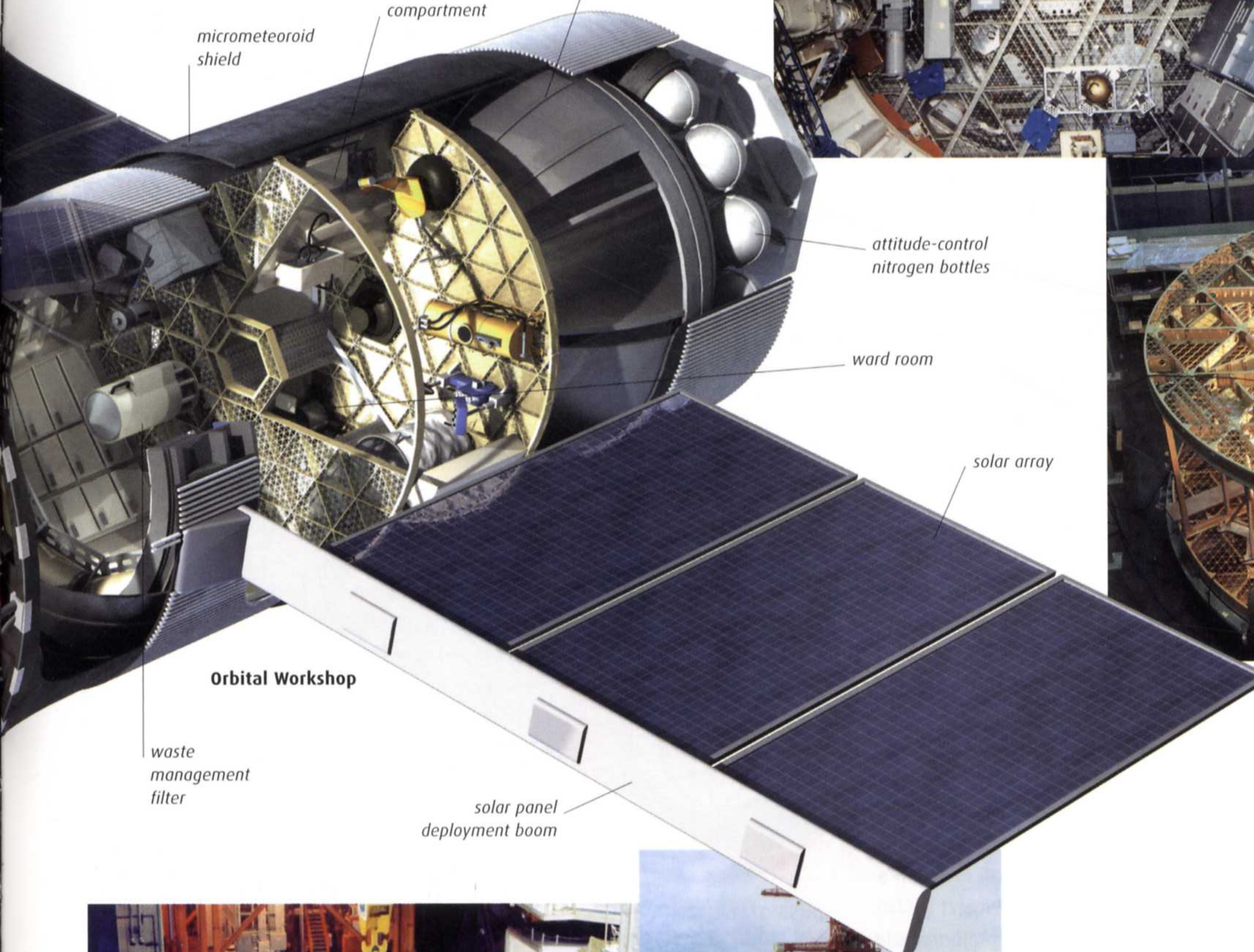
Skylab

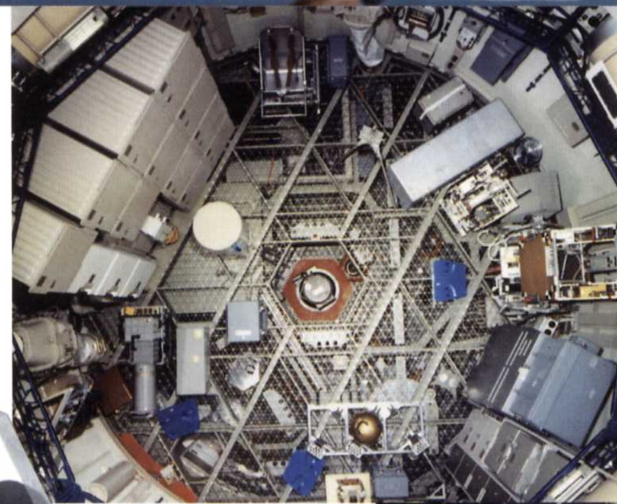
Originally conceived as part of the Apollo Applications Program in the late 1960s, the first US space station was all that remained after cuts in NASA's budget. It began life as the Orbital Workshop project, a plan to launch a Saturn IB rocket into orbit with a specially prepared S-IVB upper stage. This stage would enter orbit, and an Apollo crew would then dock with it, drain its remaining fuel, and begin to fit it out as a laboratory. The Skylab that ultimately flew was carried by a Saturn V, allowing a more ambitious design that was fully fitted out on the ground before launch.

CREW	3
LENGTH (INCLUDING CSM)	36.1m (118ft 6in)
MAXIMUM DIAMETER	6.6m (21ft 7in)
TOTAL MASS	34,473kg (76,000lb)
HABITABLE VOLUME	283 cubic m (9,985 cubic ft)
NUMBER OF DOCKING PORTS	2
DATE OF LAUNCH	14 May 1973
DATE OF RE-ENTRY	11 July 1979
MAIN CONTRACTOR	McDonnell Douglas

AIRLOCK MODULE AND MDA
Skylab's Airlock Module and Multiple Docking Adapter were built together at the McDonnell Douglas plant in St. Louis, then combined with the orbital laboratory fitted out elsewhere at the facility.

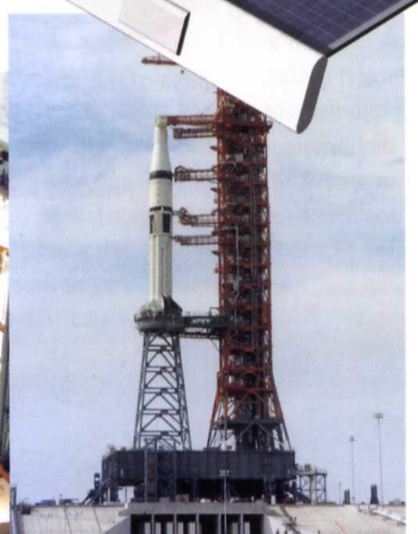
THE COMPLETE SKYLAB
This illustration shows Skylab as it would have looked had deployment gone smoothly. As it was, the launch cost the station its micrometeoroid shield and one of its two larger solar arrays.





THE ORBITAL WORKSHOP
Skylab's main section appears spacious in this view from the Airlock Module towards the aft end of the station. The upper section held a food freezer and water tanks in addition to the experimental equipment. The waste airlock can be seen in the centre of the far wall.

PUTTING IN THE FLOOR
An important early stage in the transformation of an empty S-IVB shell into an Orbital Workshop was the addition of a two-storey lightweight floor grid. This would divide the finished station into an upper laboratory and a lower living area, with a hexagonal access hole between them.

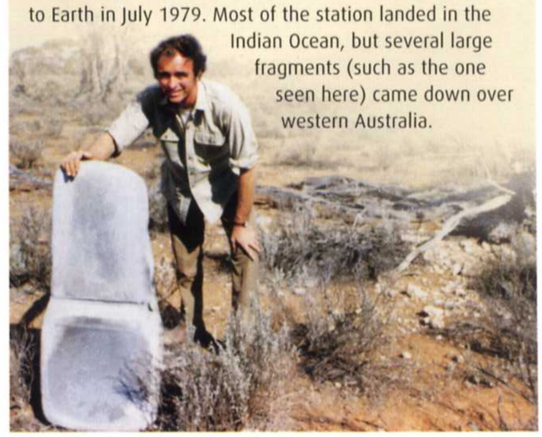


LAUNCH ODDITIES
Skylab itself was launched on a special two-stage Saturn V – here (left), the Orbital Workshop section is being lowered onto the S-II second stage. The Apollo spacecraft, meanwhile, was launched on a far smaller S-IB rocket. In order to lift off from the massive Saturn V launch structure, the rocket was hoisted onto a pedestal called the Milk Stool (above).

HISTORY FOCUS

SKYLAB'S FATE

When Skylab was abandoned in 1974, NASA believed the station would remain in orbit until the 1980s. They planned an early Shuttle mission to attach a manoeuvring engine to the station, either boosting its slowly decaying altitude or pushing it into the atmosphere for a controlled re-entry. But high drag from the atmosphere sealed Skylab's fate, and it crashed back to Earth in July 1979. Most of the station landed in the Indian Ocean, but several large fragments (such as the one seen here) came down over western Australia.



The Apollo–Soyuz project

The decision to launch a joint Soviet–American spaceflight was largely a political one, but making it a reality required engineers and astronauts on both sides to overcome a number of technical and communication problems.

15 July 1975
Apollo and Soyuz 19 launch from opposite sides of the Earth within hours of each other.

16 July 1975
Orbital manoeuvres steer the two spacecraft towards a rendezvous.

17 July 1975
The Apollo CSM docks with Soyuz 19, and Americans and Russians shake hands in space for the first time.

18 July 1975
Astronauts and cosmonauts conduct joint experiments in orbit.

19 July 1975
Apollo and Soyuz carry out docking and undocking tests. After separating for a second time, they retreat to a safe distance to continue their scientific missions.

21 July 1975
Soyuz 19 returns to Earth.

24 July 1975
The Apollo CM returns to Earth. During re-entry, a series of mishaps results in the cabin flooding with propellant gases, almost suffocating the astronauts.

The years around 1970 saw a thawing of relations between the two sides in the Cold War – an interlude called *détente*, in which the rivalry between the superpowers briefly receded. At a summit in May 1972, US President Richard Nixon and Soviet premier Alexei Kosygin brought a formal end to the Space Race with the announcement that an Apollo and a Soyuz spacecraft would rendezvous and dock in space during 1975.

The announcement had been preceded by many months of patient diplomacy at all levels. Almost as soon as he took over from James Webb in October 1968, NASA Administrator Thomas O. Paine had begun planning for a future of cooperation, rather than competition, in space. He began sounding out leading Soviet figures about the possibilities for a collaborative spaceflight, beginning with Mstislav Keldysh, President of the Soviet Academy of Sciences. Discussions continued through the Apollo moon landings and the first Salyut launches, under both Paine and his successor James C. Fletcher, until finally a plan was agreed. The two-man Soyuz 19 spacecraft would rendezvous with an Apollo CSM in Earth orbit, on a mission called the Apollo–Soyuz Test Project (ASTP).

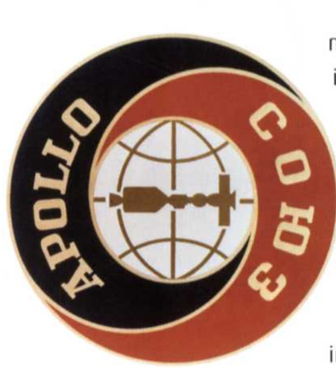
Although the main benefits of the project would be political, there were also practical implications. A system for docking Soviet and American spacecraft would open up new options for potential rescue missions should a spacecraft become stranded in Earth orbit. ASTP would also keep NASA in the manned spaceflight game during the long development of the Space Shuttle (see following chapter). In the longer term, the potential for technical advances and cost savings from pooled expertise was irresistible.

While the engineers worked feverishly on developing a system for uniting two defiantly incompatible spacecraft (see panel, above), the astronauts had their own barriers to overcome. NASA's crew consisted of Thomas Stafford, Vance Brand, and Deke Slayton, effectively NASA's chief astronaut (see p.94). The Soyuz 19 crew were to be Alexei Leonov (see panel, below) and Valery

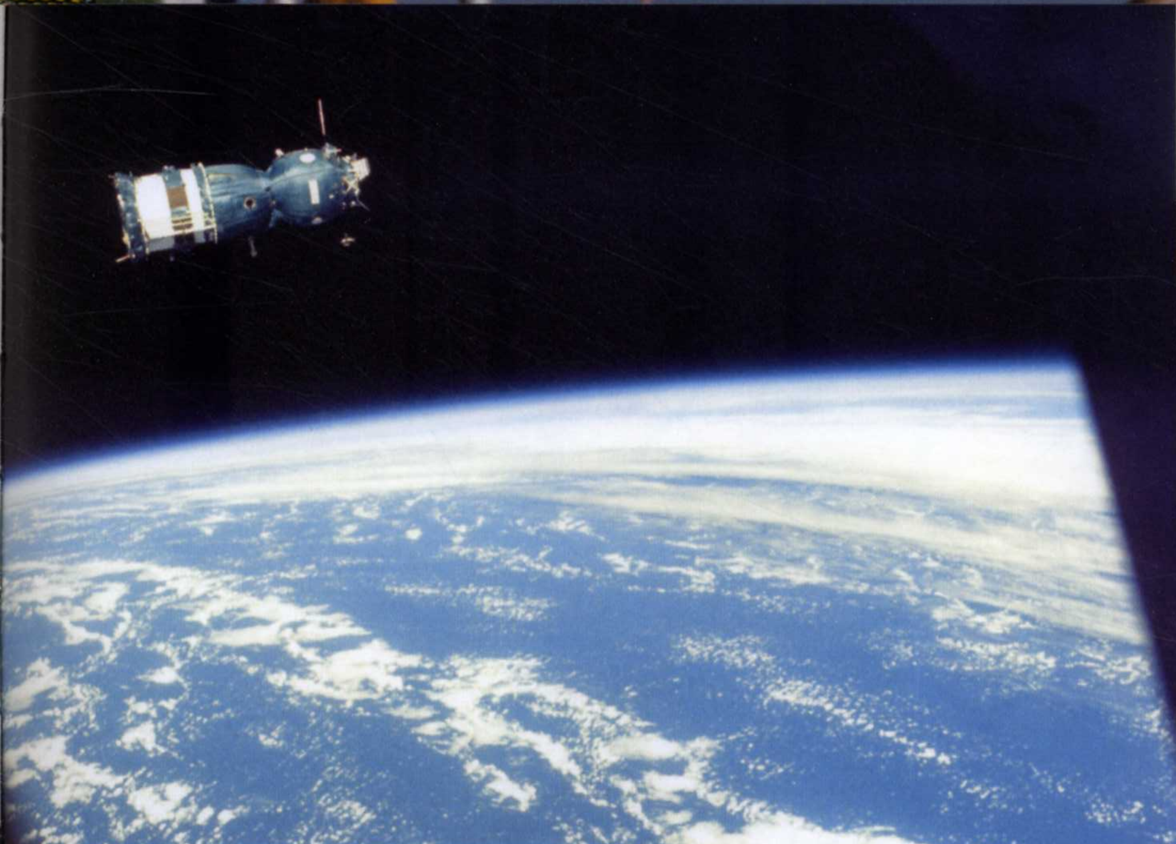
TECHNOLOGY

THE ASTP DOCKING MODULE

Docking the Apollo and Soyuz modules would be a major challenge – the docking attachments on each spacecraft were incompatible, as were the atmospheres inside them. To solve these problems, the engineers designed an adaptor with suitable docking points at either end, and an airlock system in between, to allow the crews to make a gradual transition from one atmosphere to the other. During launch, the adaptor module – which was 3.15m (10⅓ft) long with a diameter of 1.40 m (4½ft) – was stowed beneath the Apollo CSM, just like a lunar module. After reaching orbit, the CSM turned round, linked with the docking module, and pulled it free.



MISSION INSIGNIA
The Apollo–Soyuz mission logo, with its stylized representation of the docked spacecraft, was a Soviet design.



MEETING IN SPACE
(Left) Soyuz 19, photographed from the Apollo CSM, as it approaches for docking. (Above) Alexei Leonov and Thomas Stafford hold the flags of their respective countries during a broadcast for Soviet television.

PLANNING ON EARTH
NASA built a mock-up Soyuz at Houston for use in training. Here cosmonaut Leonov and astronaut Stafford pore over procedures for the orbital rendezvous.

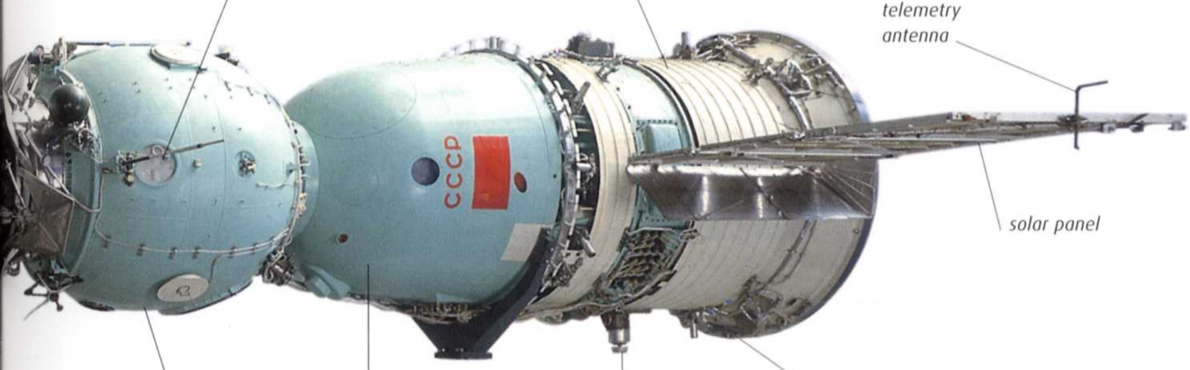
APOLLO–SOYUZ
Joined together, the Apollo and Soyuz spacecraft clearly show their origins on rival sides of the Space Race. The block in the centre is the docking module, which allowed the two incompatible spacecraft to join together.

Kubasov. All five crew members, as well as their backups, had to go through intensive language training alongside their other studies. The crews, and many other members of the technical staff, also visited each other's training facilities and familiarized themselves with the other spacecraft's systems

Orbital union

Soyuz 19 took off from Baikonur Cosmodrome on 15 July 1975, with the Apollo spacecraft (it had no call sign or other designation and was known simply as *Apollo*) joining it from Cape Canaveral about seven hours later. A day of orbital manoeuvres brought the spacecraft to their rendezvous, and they docked at 16:10 GMT on 17 July (see pp. 176–77). Astronauts and cosmonauts transferred from one spacecraft to the other several times, and though the tasks they carried out were largely related to ceremony and public relations, there were also practical tests of the docking module, with the spacecraft briefly undocking and then uniting once again, before finally going their separate ways.

After a successful return to Earth for both spacecraft, the crews did the usual round of press conferences, photocalls, and ceremonials. But the political mood was changing again, and as relations cooled once more between the superpowers, there would be no repeat of the mission. It would be another two decades before a second handshake in orbit would take place.



BIOGRAPHY

ALEXEI LEONOV

Born in Siberia, Alexei Arkhipovich Leonov (b.1934) showed early interest in both art and aviation but eventually joined the Soviet Air Force, where he was selected for the first cosmonaut trainee group in 1960. He first flew aboard Voskhod 2 in 1965, becoming the first man to walk in space (see p.102). Although he did not fly again until Soyuz 19, he had been scheduled for several other missions, including a proposed flight around the Moon and the cancelled second mission to Salyut 1. After his second flight, he became head of the cosmonaut team at Star City, eventually retiring with the rank of General in 1991 to concentrate once again on painting.

EXPERIENCE

THE SUPERPOWERS MEET IN SPACE

MISSION MEMENTO
Each crew carried two identical halves of this plaque – after exchanging sections, each took a complete version back to Earth.

A handshake in orbit

The Apollo–Soyuz Test Project was a triumph of early cooperation between the Soviet and American space programmes, with engineers working for many years to make two separately evolved spacecraft operate together. In July 1975, however, it ultimately came down to the skill of five people in orbit.

The numberless Apollo soared into the Florida sky atop its Saturn IB launcher on the afternoon of 15 July 1975, racing in pursuit of the Soviet Soyuz 19 that had launched earlier in the day. On reaching space, Command Module Pilot Vance Brand cried in Russian "Miy Nakhoditsya na orbite!" ("We are in orbit!"). A little under an hour later, the Apollo CSM separated from the S-IVB upper stage, and turned around to pull the Docking Module (DM) out of the stowage space normally reserved for a Lunar Module.

On 16 July, Soyuz performed several engine burns to help modify its orbit. Meanwhile, Apollo, after a perfect docking and extraction manoeuvre, made a series of its own burns to gradually take it up with the Soyuz, bringing the two craft together on the cosmonauts' 36th orbit of Earth.

Awaking early on 17 July, the Apollo crew sighted Soyuz at 1pm Houston time, and made radio contact moments later. The cosmonauts greeted their American counterparts enthusiastically:

TOGETHER IN SPACE
The crew of Soyuz 19 left Earth 7½ hours before Apollo. Over the next two days of flight, both crews adjusted their sleep to synchronize with each other better. The spacecraft stayed locked together for a little under two days, during which time the Americans got to enjoy a banquet of Soviet space food aboard the Soyuz.

Deke Slayton: Soyuz, Apollo. How do you read me?

Valery Kubasov: Very well. Hello, everybody.

DS: Hello, Valery. How are you? Good day, Valery.

VK: How are you? Good day.

DS: Excellent ... I'm very happy. Good morning.

Alexei Leonov: Apollo, Soyuz. How do you read me?

DS: Alexei, I hear you excellently. How do you read me?

AL: I read you loud and clear.

DS: Good.

A first measure of separation revealed that the two craft were 222km (138 miles) apart. Over the next three hours, a series of manoeuvres by Apollo closed the gap. Given approval for docking, Leonov rolled Soyuz 19 towards the approaching Apollo, while US Commander Tom Stafford guided the American spacecraft in to a perfect rendezvous at 16:10.

IN TRAINING
The crew of Apollo and Soyuz 19 (left to right: Brand, Leonov, Stafford, Kubasov, and Slayton) formed close ties during their months of preparation.

"Man, I tell you, this is worth waiting **16 years** for!**"**

Deke Slayton catching his first view of the Earth from space, 15 July 1975

HISTORIC HANDSHAKE
Looking into the cable-strewn Soyuz Orbital Module, Stafford's first words were "Looks like they got a few snakes in there, too." Then he called "Alexei, our viewers are here – come over here, please."

The Apollo crew had closed the hatch to the DM in case anything went wrong on final approach, while the cosmonauts had retreated to their Descent Module. As Deke Slayton reopened the DM hatch, a smell of burning glue from inside caused brief alarm and a delay while they waited for the air to clear. Slayton and Stafford now entered the DM and sealed themselves in as the atmosphere slowly adjusted to match that on Soyuz, while a Soviet announcer broadcast a message from premier Leonid Brezhnev:

"To the cosmonauts Alexei Leonov, Valery Kubasov, Thomas Stafford, Vance Brand, Donald Slayton. Speaking on behalf of the **Soviet people**, and for myself, I congratulate you … The whole world is watching with rapt attention and admiration of your joint activities in fulfillment of the complicated programme of scientific experiments. The docking has confirmed the correctness of the technical decisions developed and realized by **cooperative friendship**."

Leonov and Kubasov opened the hatch on their side, then Stafford opened the final hatch and looked out into the Soviet spacecraft. Leonov was waiting to greet him, and the two commanders shook hands high above the French city of Metz.

MEETING PRESIDENT FORD
The US President took a keen interest in the Apollo–Soyuz rendezvous, questioning the astronauts and cosmonauts closely during a radio link-up. He later welcomed the US and Soviet crews to the White House.

19 April 1971
The unmanned Salyut 1 DOS station is launched from Baikonur by a Proton rocket.

23 April 1971
Soyuz 10 is launched, carrying the intended first Salyut crew of Vladimir Shatalov, Alexei Yeliseyev, and Nikolai Rukavishnikov (one of the design team). Later in the day, an attempt to board Salyut 1 fails when the docking system will not fully engage.

24 April 1971
Soyuz 10 returns to Earth.

10 May 1971
An investigation concludes that the Soyuz 10 docking failure was probably due to a fault on the spacecraft, not the station.

6 June 1971
Soyuz 11 is launched with an improved docking mechanism, and successfully docks with Salyut 1 a day later. The three-man crew begin a 23-day mission aboard the station.

29 June 1971
The crew of Soyuz 11 are killed returning to Earth.

10 October 1971
Salyut 1 breaks up on re-entry.

An outpost in orbit

Recognizing that it had lost the race for the Moon, the Soviet Union rapidly switched its space programme to focus on the exploitation of Earth orbit.

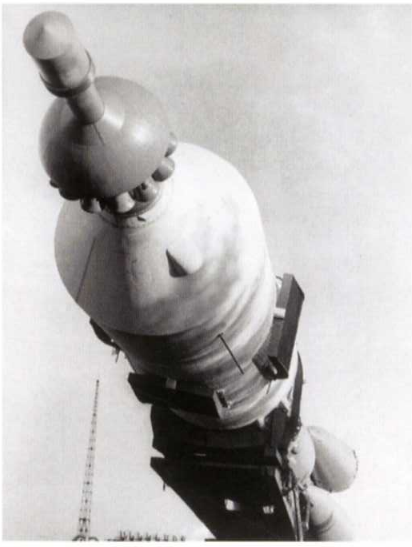
While the engineers of OKB-1 had spent most of the late 1960s developing technology for a Soviet trip to the Moon, by the end of the decade they had little to show for it but the Soyuz spacecraft. Meanwhile, the rival design bureau led by Vladimir Chelomei had been garnering political support for a series of manned military space stations known as Almaz. The Almaz station would be launched using Chelomei's powerful Proton rocket (see p.210), and cosmonaut crews and supplies would travel to and from it using the almost equally massive TKS ferry vehicle.

Following the decision to abandon manned lunar efforts and pretend there had never been a race with Apollo, launching a space station suddenly became a priority. Of course, there was still the question of whether a cosmonaut could survive the proposed month-long missions in weightless conditions – at the time, no cosmonaut had flown for longer than five days. The Soyuz 9 mission was to change all that, with Andrian Nikolayev and Vitaly Sevastyanov spending some 18 days in orbit.

A change of plan

Despite this success, other elements of the project were not going well. Both the station and the TKS ferry were taking a long time to develop, and there were strong reservations about using the new and unreliable Proton to launch manned missions. Despite intense hostility between Chelomei and Vasili Mishin, engineers from their two bureaux conspired to find a solution to the problem, developing the long-duration orbiting station (DOS is its Russian acronym), a hybrid combining elements of Almaz with ideas from OKB-1's own ambitious plan for a modular station. Soyuz spacecraft, launched on an R-7-derived rocket, would service the hybrid station.

The DOS plan helped speed up development, and by April 1971, the first of the hybrid stations was ready for launch. Salyut 1, as it was called (in "salute" to Yuri Gagarin's historic first flight a decade earlier), was launched by a Proton rocket and entered orbit some 264km (164 miles) above the Earth. With the station safely deployed, its intended first crew took off aboard Soyuz 10, rendezvousing on 24 April. The spacecraft managed to dock with Salyut 1, but an electrical fault prevented the cosmonauts swinging aside the bulkhead between the two spacecraft and gaining access to the station. After several attempts, they undocked and returned



SOYUZ ON THE PAD
A Soyuz rocket with Soyuz 9 spacecraft, shroud, and escape tower in place is raised into an upright position prior to launch.

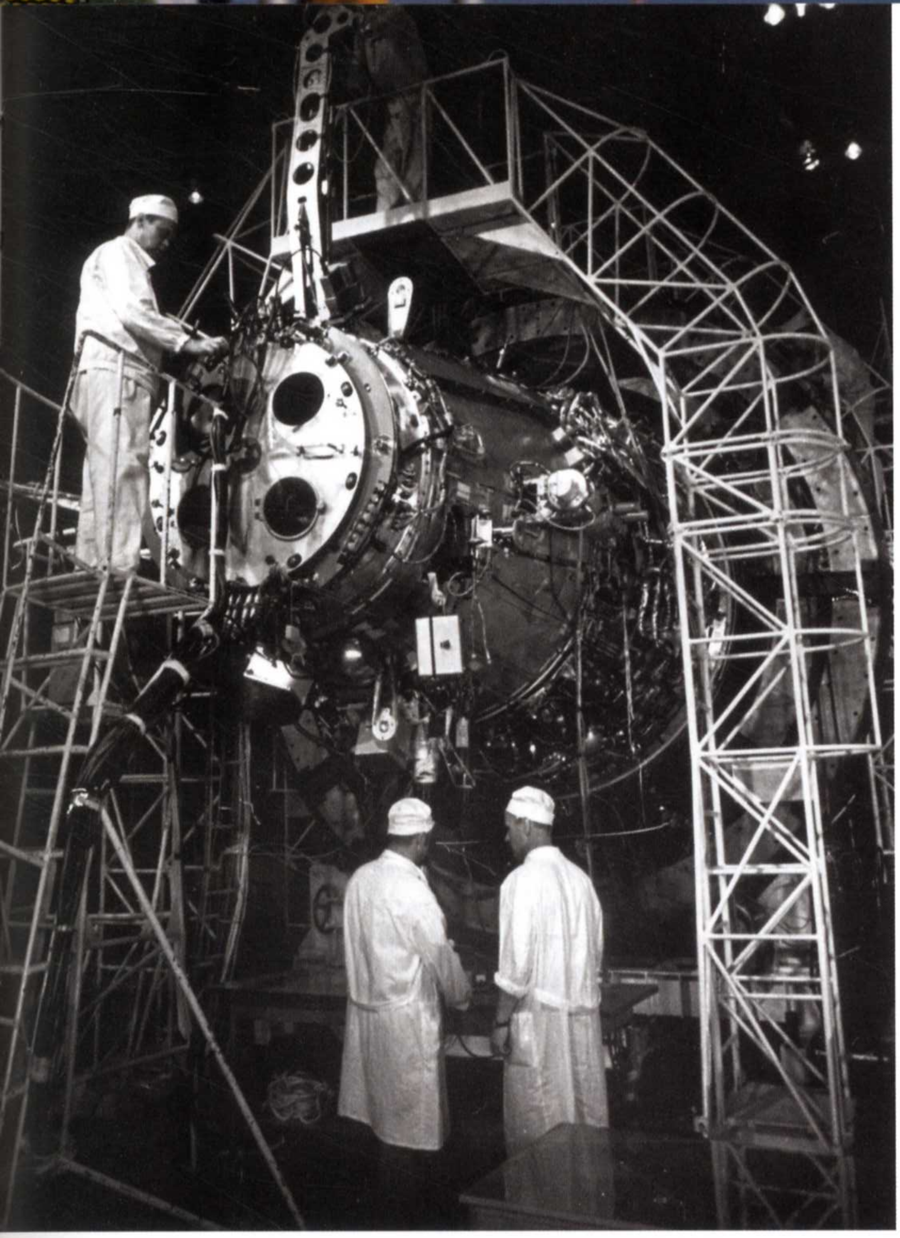
IN THE FACTORY
Engineers work on fitting the Soyuz-compatible docking port to the Almaz-derived components of Salyut 1. The 2m (80in) diameter compartment fitted to the narrower end of the station's main body.

LOST CREW
The crew of Soyuz 11 pose for a photo during training, Left to right are Commander Georgi Dobrovolsky, Test Engineer Viktor Patsayev and Flight Engineer Vladislav Volkov.

HISTORY FOCUS

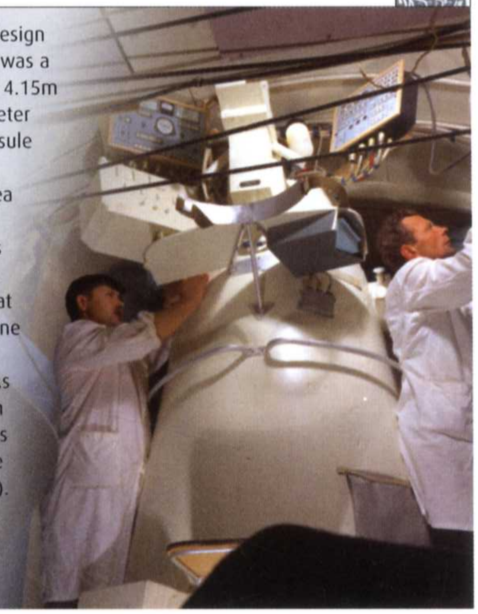
STAR CITY

Since 1960, Soviet cosmonauts have lived and worked at the specially built town of Zvyozdny Gorodok near Moscow. The name means "little town of stars" in Russian, but in the West it is usually known as Star City. The town is home to the Gagarin Cosmonaut Training Centre, where facilities include full-size mock-ups and simulators of all the major Soviet and Russian space vehicles (including the Salyut stations), centrifuges for *g*-force training, and large water tanks for simulating weightless operations. A nearby airfield hosts aircraft that fly parabolic paths to simulate weightlessness. In the Soviet era, Zvyozdny Gorodok was a restricted area, but today foreign visitors include astronaut trainees, space enthusiasts, and tourists. Many cosmonauts and their families still live in the town.



TECHNOLOGY

SALYUT DESIGN



Vladimir Chelomei's original Almaz design – which formed the basis of Salyut – was a stepped cylinder with two segments 4.15m (13ft 7in) and 3m (9ft 10in) in diameter and 11.6m (38ft) long. A conical capsule at the forward end would allow it to be launched with a crew, but this idea was later abandoned. At the rear, a docking port would allow Chelomei's manned TKS ferries to approach. The Salyut DOS configuration developed at OKB-1 replaced the ring-shaped engine around the aft docking port with a Soyuz-based unit that sat centrally. As a result, a new docking system (with an airlock transfer compartment) was added to the forward end, giving the station a total length of 14.6m (48ft). The flown Almaz stations had fewer changes – the rear docking port was modified to accommodate Soyuz.

to Earth – official Soviet press releases claimed the mission was only ever intended as a docking test. Six weeks later, Soyuz 11 tried again – and this time, everything went smoothly.

After docking and moving into the station, the three-man crew established a round-the-clock schedule. While one person slept, another was off duty, relaxing, eating, and using various exercise devices to stave off the effects of weightlessness. The third, meanwhile, manned the station's array of scientific experiments, which included remote-sensing instruments to study the Earth, telescopes and other detectors for astronomy, and various biomedical experiments that frequently saw the cosmonaut as both scientist and guinea-pig.

Tragedy strikes

Things went well, and daily television broadcasts were sent back to Earth, until on 16 June a minor fire broke out. It was soon extinguished and was never a serious threat, but the scare led to the mission being cut short. Salyut 1 was put into automatic mode and its crew prepared to return to Earth, but then tragedy struck. As the re-entry module separated from the rest of the Soyuz 11 spacecraft, an explosive bolt forced open a pressure valve, allowing air to escape from the cabin and suffocating the cosmonauts before they re-entered the atmosphere.

The loss stunned the Soviet public, who had grown familiar with the cosmonauts through their broadcasts. It also grounded the Soyuz spacecraft, and with no other way of servicing the Salyut 1 station, its operators reluctantly allowed its orbit to decay, until it broke up on re-entry in October 1971.

ABOARD SALYUT 1
During more than three weeks on the station, the crew adapted well to life in orbit. Volkov and Dobrovolsky decided to grow beards, but Patsayev shaved regularly.

3 April 1973
Salyut 2, the first Almaz station, reaches orbit, but control is lost 22 days later, before it can be occupied.

24 June 1974
Salyut 3 is successfully launched into orbit.

4 July 1974
The crew of Soyuz 14 join Salyut 3, staying onboard for 14 days.

26 December 1974
A Proton rocket launches the DOS station Salyut 4.

11 January 1975
Soyuz 17 is launched, carrying the first crew to Salyut 4.

25 January 1975
Salyut 3 breaks up on re-entry after only one spell of occupation.

24 May 1975
Soyuz 18 takes a second crew to Salyut 4.

22 June 1976
The Almaz-based Salyut 5 launches successfully.

24 February 1977
Salyut 5 is abandoned following two successful manned missions.

Reinventing Salyut

The hiatus created by the Soyuz 11 tragedy gave Vladimir Chelomei's military Almaz project a chance to catch up with the hybrid space station under cover of the Salyut name.

IMPROVED HYBRID
The Salyut 4 design used three large solar panels that could rotate to face the Sun. It also had a new automatic docking system and improved water reclamation.

The Soviet Union's next attempt at a space station launch, when it came, was to be another hybrid similar to Salyut 1. Launched in July 1972, the station was lost after a malfunction in the second stage of its Proton launch vehicle. Had it survived to orbit, this would have been Salyut 2 – but, as a failure, the Soviets simply ignored it.

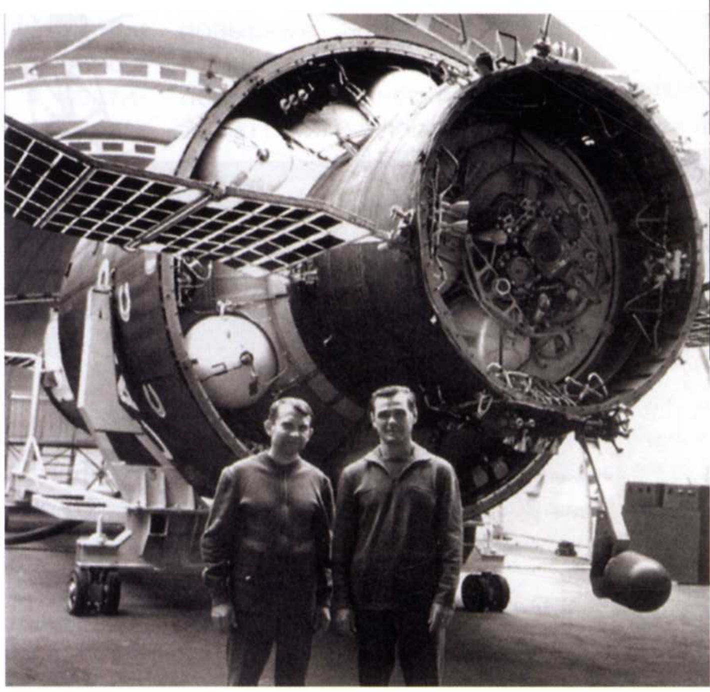
Doubts about the reliability of the Proton rocket had forced Chelomei to adapt his original Almaz design so that it could dock with Soyuz, but by early 1973 the first Almaz and a new, upgraded hybrid were both ready. The Almaz station was launched first, and once in orbit on 3 April was officially announced as Salyut 2. Official press releases made no mention of the fact that this was a different type of station, intended largely as a manned spy satellite, but the difference in telemetry signals offered Western experts a clue to its true purpose. All seemed to be going well, and the first crew were preparing for launch, when Salyut 2 suddenly fell silent, victim of a catastrophic break-up in orbit.

As Soviet investigations soon traced the problem back to a fire that started in the Almaz propulsion unit, there was no reason to delay the hybrid station ready on the ground, and this was launched a month later, on 11 May. However, gremlins struck again as a fault in the propulsion system left the station spinning out of control, beyond hope of recovery. This time, the Soviets attempted to disguise the station as a failed satellite launch, named Cosmos 557.

Some success at last

Following these embarrassments, manufacture of both types of station was delayed for almost a year (in the interim, a pair of short-duration Soyuz-only missions kept up the Soviet presence in orbit). The next Almaz-type station was finally ready for launch in June 1974, and after a thorough orbital check-up this officially became Salyut 3. In early July, Pavel Popovich and Yuri Artyukhin docked with the station aboard Soyuz 14. As well as operating the reconnaissance camera, they conducted a number of remote-sensing experiments (see p.244) during their 16-day mission. Rigorous exercise meant that they

ALMAZ CONSTRUCTION
A military Almaz station nears completion at the Khrunichev factory near Moscow. Note the payload shroud, ready to be put in place before launch.



INSIDE AND OUTSIDE SALYUT 3
(Left) Cosmonauts Pavel Popovich and Yuri Artyukhin pose in front of the Almaz station a few days before launch. Above them is the docking port, surrounded by the manoeuvring engines.
(Above) A rare television picture from onboard a military Salyut shows Popovich and Artyukhin relaxing during free time. Even though it would operate in weightlessness, Salyut 3's interior was given a distinct floor and ceiling to help its crew adapt.

returned to Earth in far better shape than previous long-duration cosmonauts. In late-August, Soyuz 15 set off, carrying a second crew intended for Salyut 3. But bad luck struck again, when the spacecraft was unable to make a successful rendezvous. Later in September, the station released a capsule containing the film from its cameras, and then it was left to its fate, breaking up in early 1975.

By this time, a new hybrid station (similar to Cosmos 557) was already in orbit. Salyut 4 was a significant advance for the programme, with a range of new features that made it more reliable and comfortable for the crew and a higher, more stable orbit. The first crew launched aboard Soyuz 17 on 11 January 1975 and stayed in space for a new record of 30 days, during which they adapted well to conditions and carried out a variety of experiments.

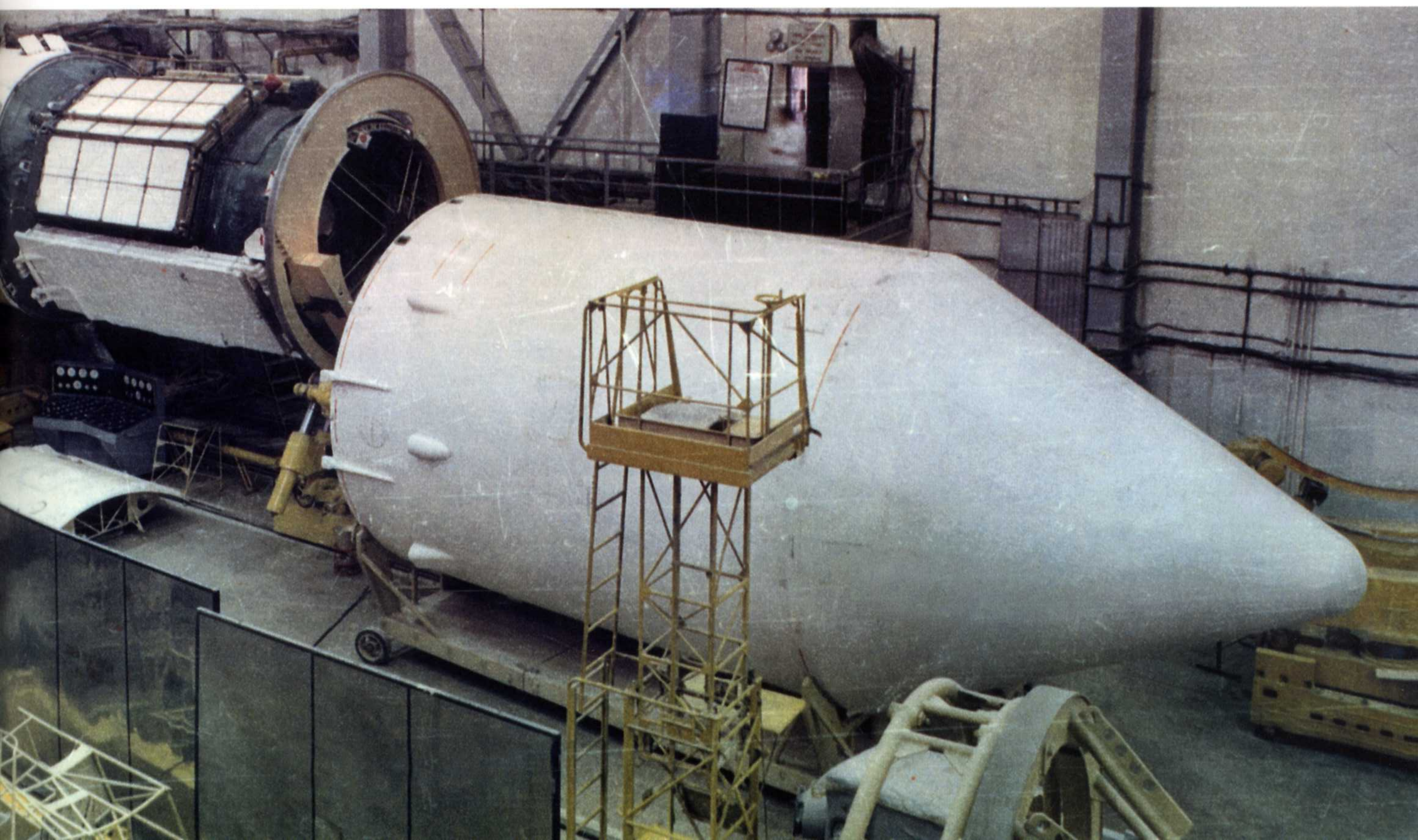
The launch of a second crew, on 5 April, ended in a dramatic escape after a rocket stage shut down prematurely and the Soyuz spacecraft had to make an emergency re-entry from an altitude of 180km (112 miles). A new replacement crew took off aboard Soyuz 18 on 24 May. Pyotr Klimuk and Vitali Sevastyanov remained in orbit for 63 days, but by the time they completed their planned tour of duty, the station was deteriorating, its windows fogged and mould growing on the walls.

TECHNOLOGY

THE SOKOL SPACESUIT

While Vostok-era cosmonauts wore pressure suits for safety reasons, by the Soyuz era the spacecraft had become a shirtsleeve environment. However, the loss of the Soyuz 11 crew changed all this, and a new suit, the Sokol, was introduced in 1973. Sokol was not intended for spacewalks – only for use in the event of an accident and during dangerous times such as re-entry. It is a two-layer suit, with a skin of rubberized synthetic material beneath an outer layer of canvas. The boots and hinged helmet are integrated into the suit, while the gloves are removable and lock into place on aluminium rings. Early versions of the suit came in two pieces that zipped together around the waist, but later variations (still in use today) are one-piece: the cosmonaut climbs into the suit through a V-shaped opening, an overlapping flap seals the inner skin, and zippers close the canvas layer. A ventilation system blows cabin air through the suit, but if pressure falls, it switches over to a bottled oxygen supply. The suit weighs 10kg (22lb) and is designed to keep the wearer alive for up to two hours in a vacuum. It is also intended to float in the event of an emergency splashdown.

Salyut 5 was the last Almaz station. Essentially the same as Salyut 3, this time the station carried materials science experiments as well as its main reconnaissance payload. The first crew, Boris Volynov and Vitali Zholobov, joined the station in July 1976, two weeks after its launch, and remained in space for 49 days. They left the station ahead of schedule after Zholobov in particular developed psychological problems. There were also suspicions of toxic gas in the cabin, but it was later reoccupied (after a failed attempt at docking by the crew of Soyuz 23), for a further 16 days by the crew of Soyuz 24.



29 September 1977
Salyut 6 reaches orbit.

10 December 1977
The crew of Soyuz 26 are launched on a 96-day mission to Salyut 6.

11 January 1978
Soyuz 27 docks to the spare port on Salyut 6, bringing two cosmonauts on a five-day visit.

22 January 1978
Progress 1, the first unmanned supply ferry, docks with Salyut 6.

19 June 1981
The Cosmos 1267 space tug docks with Salyut 6.

19 April 1982
Salyut 7 is launched.

14 May 1982
Salyut 7's commissioning crew arrive at the station aboard Soyuz T-5.

8 June 1985
Soyuz T-13 makes a manual docking with the deactivated Salyut 7 to bring it back online after a power failure.

17 November 1986
The final Salyut 7 mission is curtailed when Commander Vladimir Vasyutin falls ill.

The last Salyuts

Salyuts 6 and 7 combined the best elements of earlier military Almaz and civilian hybrid stations. They also added some innovations that allowed them to operate more effectively and for far longer.

When Salyut 6 was launched into orbit in September 1977, it represented a great leap forward for the Soviet space programme. The most significant change was that its engines had an off-axis design, allowing for a docking port at either end of the station. The ability to dock a spacecraft at either end of the station was a huge advance: unmanned supply ferries would now be able to come and go while the crew's own spacecraft remained safely docked; the station could welcome visitors or hand over from crew to crew without being uninhabited for long periods; and if a visiting crew left their new spacecraft with the station and returned in the older one already in orbit, Salyut missions would no longer be limited by the Soyuz capsule's relatively short operational life.

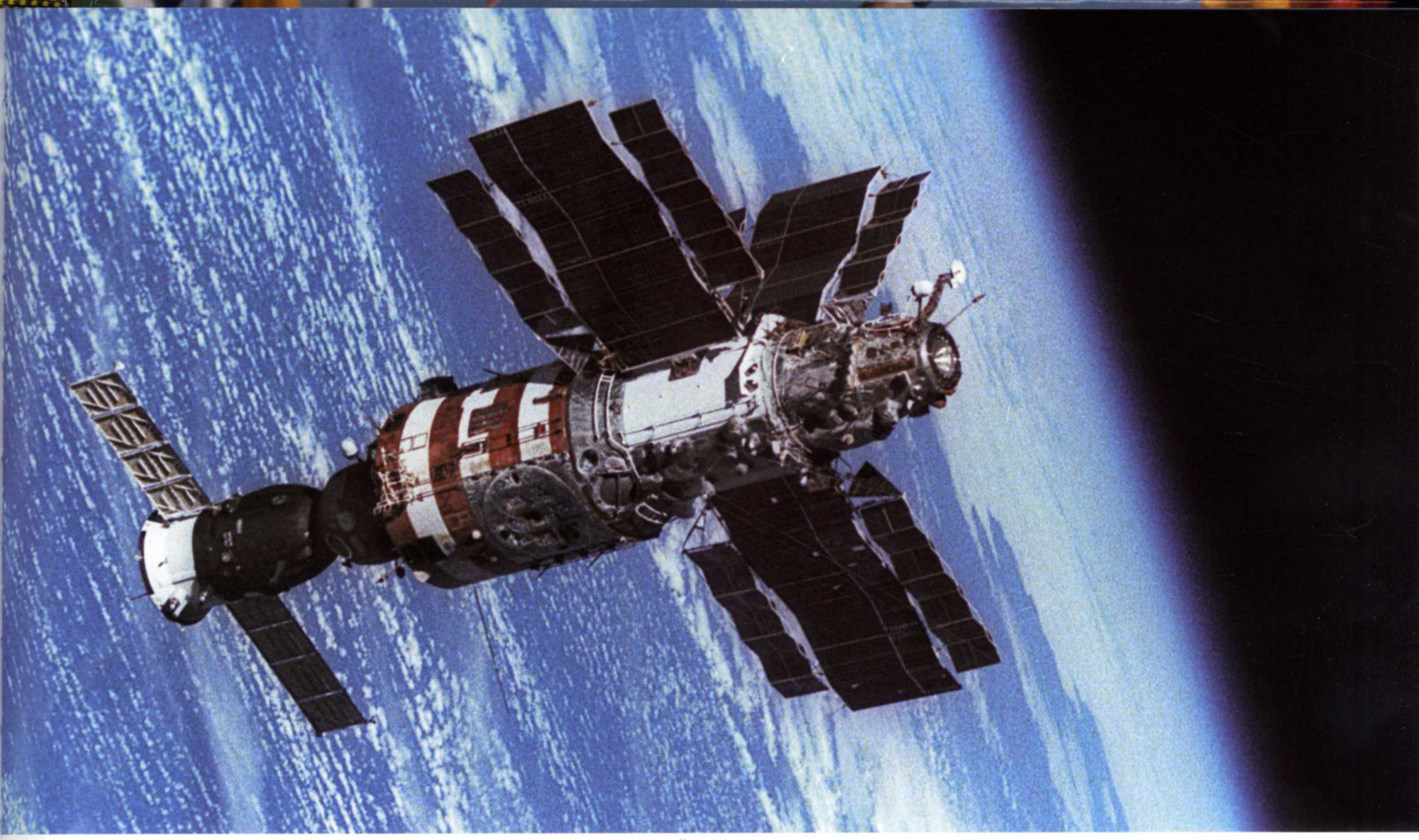
LIFE ON SALYUT 7
(Above) The crew of Soyuz T-12, Vladimir Dzhanibekov, Svetlana Savitskaya, and Igor Volk relax onboard the station. (Below) Dzhanibekov with Viktor Savinykh during their mission to revive the station in 1985.

The career of Salyut 6

If all these plans were to become a reality, though, Salyut 6 would need more luck than its predecessors, and things did not start well. The first crew, launched aboard Soyuz 25, had to turn back frustrated when the docking mechanism between station and spacecraft failed to lock. Things went better for Soyuz 26, and Georgi Grechko and Yuri Romanenko became the first full-time crew. After commissioning the station and beginning its astronomy and Earth-science programmes, they received a visit from Soyuz 27, and later unloaded the first cargo from a Progress supply ferry (see p.210). Later in the 96-day flight, a second guest crew visited, including Czech cosmonaut Vladimir Remek (see p.240).

When Grechko and Romanenko finally returned to Earth, it was aboard the Soyuz 27 spacecraft, left in orbit after its original crew had returned on Soyuz 26. This marathon formed a template for later Soviet space station operations – the only thing it did not attempt was a crewed handover. Instead, Salyut 6 was returned to automatic mode until the arrival of Soyuz 29 in June 1978. The new crew were Vladimir Kovalyonok and Alexander Ivanchenkov. During their marathon 140-day mission, they welcomed three Progress ferries and two visiting crews, with Polish and East German guest cosmonauts, and expanded the station's scientific programme into materials science. Two six-month tours then followed, in 1979 and 1980. By the time the final 75-day mission ended, with the return of Soyuz T-4 in May 1981, preparations were well underway for the next station. Before Salyut 6 was decomissioned in July 1982, it received one final visitor, the unmanned spacecraft Cosmos 1267, which was a test of Chelomei's TKS space tug, flying at last.

SALYUT 6
The latter generation of Salyut space stations incorporated the best features of the Almaz design – such as the environmental systems and gyrodynes (electrically powered stabilisers that oriented the station in orbit without wasting propellant) – together with successful elements from Salyut 4, most notably the improved power and navigation systems.

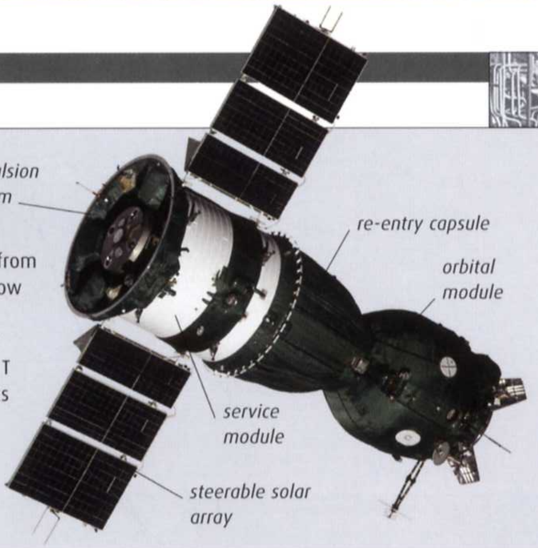


SALYUT 7 IN ORBIT
The layout of Salyut 7 surprised those who had expected the next station to have a modular design (like the later Mir). Nevertheless, the station proved that Salyut 6's four-year lifetime was no fluke and that stations could operate for long periods in orbit.

TECHNOLOGY

THE SOYUZ T SPACECRAFT

A new generation of Soyuz spacecraft entered service during the lifetime of Salyut 6. Soyuz T shared the same basic design as the previous spacecraft, but many of its elements were improved. The new Igla rendezvous system received data from the station to make docking more reliable, the thrusters now used the same fuel as the main engine, and solar panels, dropped from nearly all Soyuz capsules in the review after Soyuz 11, were reintroduced. Most significantly, the Soyuz T was now able to accommodate a crew of three cosmonauts in full spacesuits. The first manned mission of the new vehicle was a brief visit to Salyut 6 in June 1980, and Soyuz T continued to fly until 1987, when it was replaced by a new upgrade, the Soyuz TM.



The last Salyut

Launched in April 1982, Salyut 7 was a slightly upgraded version of its predecessor. The improved orbital life of the Soyuz T capsule (see panel, above) reduced the need for regular visits by guest crews to exchange the docked spacecraft, but visits were still needed from time to time, as missions grew longer.

The new station was launched in an almost empty state – once Anatoli Berezovoi and Valentin Lebedev were aboard, scientific equipment and consumables were supplied by Progress (and later TKS) ferries. The crew soon welcomed visitors from Soyuz T-6, including French cosmonaut Jean-Loup Chrétien. In August, the visit of Soyuz T-7 brought with it the second female cosmonaut, Svetlana Savitskaya. Berezovoi and Lebedev remained in orbit for 211 days, smashing previous records. The second long-stay crew, who arrived the following April, stayed for only five months, but a three-man mission in 1984 saw Leonid Kizim, Vladimir Solovyov, and Oleg Atkov extend the record to 236 days, and included a visit by Indian cosmonaut Rakesh Sharma.

Early in 1985, with the unmanned station in automatic mode, an electrical fault drained the batteries, and it seemed as if Salyut 7 was to be abandoned. But a rescue mission by Soyuz T-13 brought it back to life for two more long-duration missions – and this time the cosmonauts did achieve the orbital handover between crews that would be key to the next, and final, Soviet space station.

THE FIRST FEMALE SPACEWALKER
During a second visit to Salyut 7 in July 1984, cosmonaut Svetlana Savitskaya became the first woman to walk in space, during a three-hour, 35 minute EVA.

USA – NASA achievements

USA – Apollo-Soyuz

USA – Ten years of manned spaceflight

USA – Apollo 8

USA – Gemini 4

USA – Pioneer

USA – Echo 1

USSR – Vostok 1

USSR – Soyuz 4 and 5, first-day cover

USSR – Vostok 6

USSR – Mars 1

USSR – Gagarin 1964

USSR – Voskhod 2

USSR – Vostok 5

USSR – Salyut 6

USSR – Vostoks 3 and 4

USSR – Soviet space programme celebration

Rwanda

Bulgaria

Czechoslovakia

Vietnam

Cambodia

North Korea

Space Age stamps

Almost as soon as the Space Race began, its associated propaganda was put to use in ephemera of all kinds. The gallery of stamps shown here shows how space triumphs were used to shape the national image.

For all its failings, the former Soviet Union was an undoubted master of propaganda – within days of Sputnik 1's launch, the communist nation's triumph was commemorated on stamps issued not only in the USSR itself, but also across Eastern Bloc countries such as Romania and Czecholslovakia. The Soviet command economy was soon turning out other varieties of space-related ephemera, but the stamps are particularly evocative of the modernist dreams that accompanied the birth of spaceflight – representations of cosmonauts and spacecraft ranged from the self-consciously stylized and heroic to the photographic and futuristic.

While other communist countries toed the party line, they soon had their own space achievements to commemorate – as the Soviet Intercosmos programme put astronauts from countries as diverse as Vietnam, Mongolia, and Cuba into orbit.

NASA also found an eager supporter in the United States Postal Service, and stamps were issued to commemorate most US manned and unmanned space achievements. Many other nations also seized on the Space Race as a fitting subject for their stamps, and the decision over whether to depict US or Soviet missions frequently reflected the political complexion of their governments.

Mongolia

Mongolia

Nicaragua

Romania

Poland

Hungary

Cuba

Cuba

Thailand

MAY 1992: SPACE BUILDING
Astronauts Kathryn Thornton (foreground) and Thomas Akers rehearse assembly procedures for the projected, but never completed, Freedom Space Station in the open cargo bay of the Space Shuttle Endeavour. *In the background hangs the pale blue globe of the Earth.*

WORKING IN SPACE

FACED WITH FALLING BUDGETS in the wake of Apollo, NASA turned its attention to what it hoped would be cheaper methods of exploring space. The benefits of winged spacecraft had long been recognized, but such vehicles were sidelined in favour of the ballistic approach as the Space Race took hold. Now the idea was reborn in NASA's Integrated Space Transportation System – a Space Shuttle that would make routine trips to and from orbit, and a large space station that would be serviced by the new spacecraft. But there were insufficient funds for both projects, so the station was soon abandoned to concentrate on the Shuttle, which would now take on the role of orbiting laboratory as well as launch vehicle.

In the Soviet Union, meanwhile, space stations went from strength to strength, still supported by the reliable Soyuz spacecraft family. The last Soviet station, Mir, was a great leap forward with a complex, modular design. And political changes on Earth dictated that this was where the two nations would finally come together in space.

8 June 1959
NASA's X-15 hypersonic research aircraft makes its first flight.

10 December 1963
USAF cancels its X-20 Dyna-Soar programme.

12 July 1966
The first test of NASA's M2-F2 lifting body prototype is a success.

24 October 1968
The X-15 makes its 199th and final flight.

17 April 1969
The X-24A, prototype of a lifting body plannned by the USAF for potential launch on a Titan rocket, makes its first test flight.

5 January 1972
President Nixon announces that NASA's next major space project will be the development of a winged reusable launch vehicle – the Space Shuttle. Shortly afterwards, USAF signs up as a partner in the Shuttle programme, and eventually abandons its research into rocket-launched lifting bodies.

Early spaceplanes

The idea of a winged space vehicle was considered as an alternative to the ballistic capsule approach many times before NASA finally decided to develop its reusable Space Shuttle system.

The basic idea of a winged, rocket-powered space vehicle that can use aerodynamic lift to travel at least part of the way into space was first proposed in the 1930s by Eugen Sanger, a member of the German VfR rocket society. His concept involved an aircraft launched at supersonic speeds on a rocket-powered sled (see p.298). Other ideas often used some combination of a ballistic launch and a plane-like descent, such as the British MUSTARD concept (see panel, below).

The true ancestors of the Space Shuttle, however, were the hypersonic X-craft. Close relations of the Bell X-1 (see p.34), these craft could fly at more than five times the speed of sound and were tested by NACA and NASA throughout the 1950s and 1960s. Several of the later designs had stubby wings and relied on the shape of the fuselage itself to generate most of their aerodynamic lift – they are often referred to as lifting bodies. Normally carried to high altitude while attached to a larger aircraft, they fired their rocket engines on release, accelerating rapidly and following trajectories that looped up to 28km (17 miles) above the Earth, before plummeting back in a hair-raising unpowered, supersonic glide. Although NASA did not pursue the lifting body concept at the time, it has proved highly influential in plans for the next generation of spaceplanes (see p.298).

Another type of X-craft was typified by the X-15, a rocket-powered research plane piloted by Neil Armstrong and Scott Crossfield (see panel, opposite) among others. This long, slender aircraft still relied on a lift to high altitude, but with larger wings it generated more lift as it fell back to Earth. Perhaps the closest parallel of all to the Space Shuttle was the X-20 Dyna-Soar – an abandoned USAF plan for a winged aircraft that would have been launched into orbit on top of a rocket.

M2-F2
This lifting body first flew in 1966, dropped from beneath a B-52 bomber. It tested techniques for high-speed gliding that would eventually be used by the Space Shuttle.

SPIRAL
The Soviet Spiral was an orbiter to be launched from a hypersonic aircraft. It was abandoned in 1971.

Birth of the Space Shuttle

Throughout the early decades of space exploration, there were no reusable launch vehicles, and so each launch was extremely expensive. NASA's plans for a Space Shuttle, developed in the early 1970s under the administration of James C. Fletcher and announced by President Nixon on 5 January 1972, were supposed to drastically cut the costs of reaching orbit, and make routine spaceflight a reality.

With budget and political backing secured, NASA invited concepts from contractors and was deluged with a huge variety of concepts. The most popular early plan envisaged a two-stage vehicle, with the spaceplane carried most of the way to orbit by a large rocket-powered, piloted carrier aircraft – a larger equivalent of the X-15 system. When this concept was abandoned as too costly, NASA reluctantly recognized that not all of the system, now known formally as the Space Transportation System (STS), could be completely reusable.

ARMSTRONG THE PILOT
Neil Armstrong poses with the North American X-15 following a successful test flight. The hypersonic plane flew 199 flights between 1959 and 1968.

TECHNOLOGY

MUSTARD

Of the many great missed opportunities of the Space Age, the Multi-Unit Space Transport And Recovery Device (MUSTARD) is one of the most intriguing. First proposed by the British Aircraft Corporation in 1965 but abandoned a few years later, MUSTARD would have used three identical "stacked" lifting bodies, launched like a conventional rocket. The lower stages would separate and glide back to Earth at altitudes of 45–60km (28–38 miles), after pumping their remaining fuel into the orbiter stage. This would in theory allow the orbiter to reach space with full fuel tanks, potentially allowing it to continue to the Moon.

X-PLANE

The X-15 was 15m (50ft) long, with a wingspan of just 6.7m (22ft). Rear rockets powered it to a height of 108km (67 miles) and speeds of up to Mach 6.7.

BIOGRAPHY

SCOTT CROSSFIELD

Albert Scott Crossfield (1921–2006) was widely viewed as America's top test pilot – the man who often took experimental aircraft like the X-15 into the sky for the first time. After serving as a pilot and flight instructor during the Second World War, he joined NACA in 1950 but left to work for North American Aviation in 1955. In the late 1950s, he and several of his colleagues were briefly considered as pilots for a manned spaceflight.

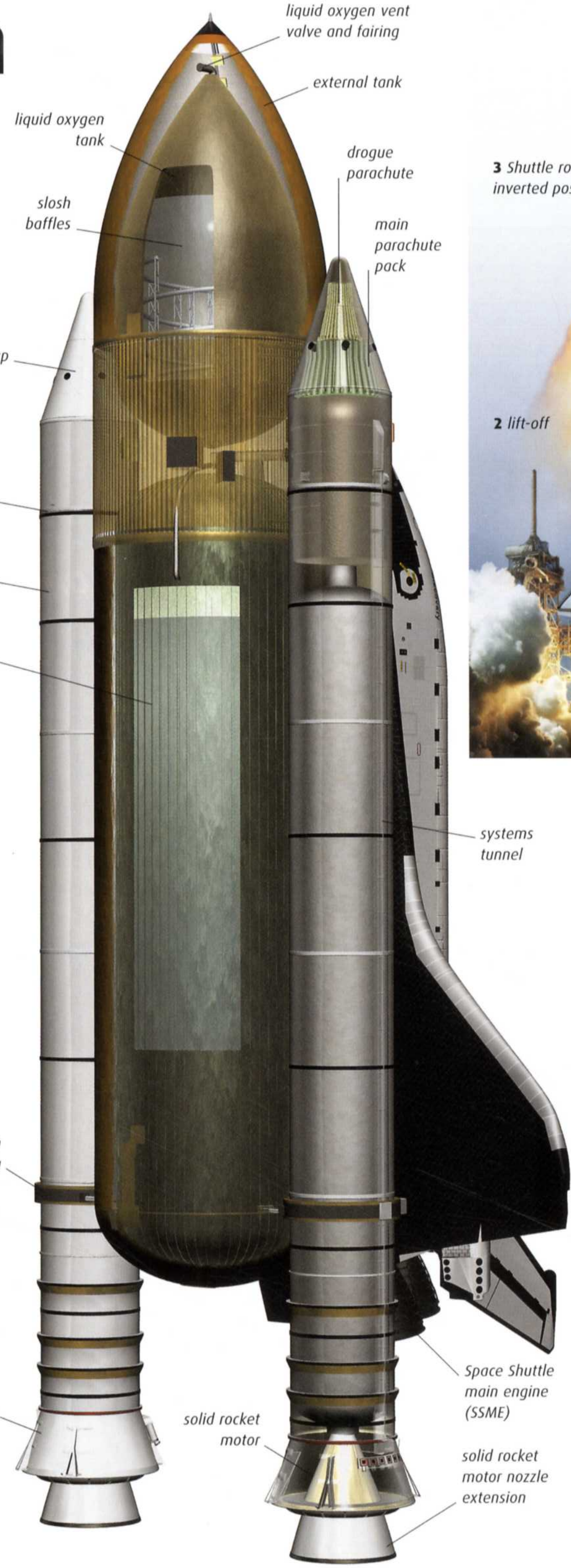
TECHNOLOGY

SPACE SHUTTLE LAUNCH AND RETURN

The Shuttle system

The final version of the Space Transportation System (STS) was a compromise born of necessity. The US military's need for a sizeable orbiter to launch its largest payloads made it impossible to design a fully reusable system, but the Shuttle is at least largely reusable. In addition to the Shuttle orbiter itself (see pp.196–97), there are three other elements – a large External Tank (ET) and two side-mounted Solid Rocket Boosters (SRBs). Each of these plays an important role in getting the Shuttle orbiter into space.

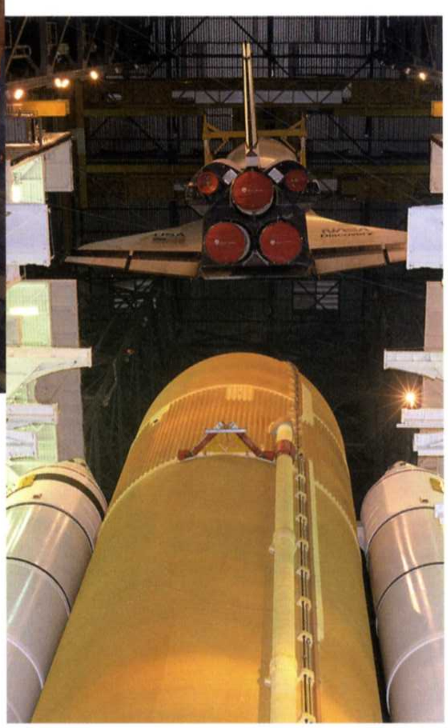
HEIGHT (TO TOP OF ET)	56.14m (149ft 7in)
MASS AT LAUNCH	2,029,203kg (4,474,574lb)
LAUNCH PROPULSION	2 x SRBs, 3 x SSMEs
TOTAL THRUST AT LIFT-OFF	3.55 million kgf (7.8 million lbf)
PAYLOAD TO LEO	24,400kg (53,700lb)
MAIN CONTRACTORS	SRB: Thiokol; ET: Lockheed Martin; SSME: Rocketdyne



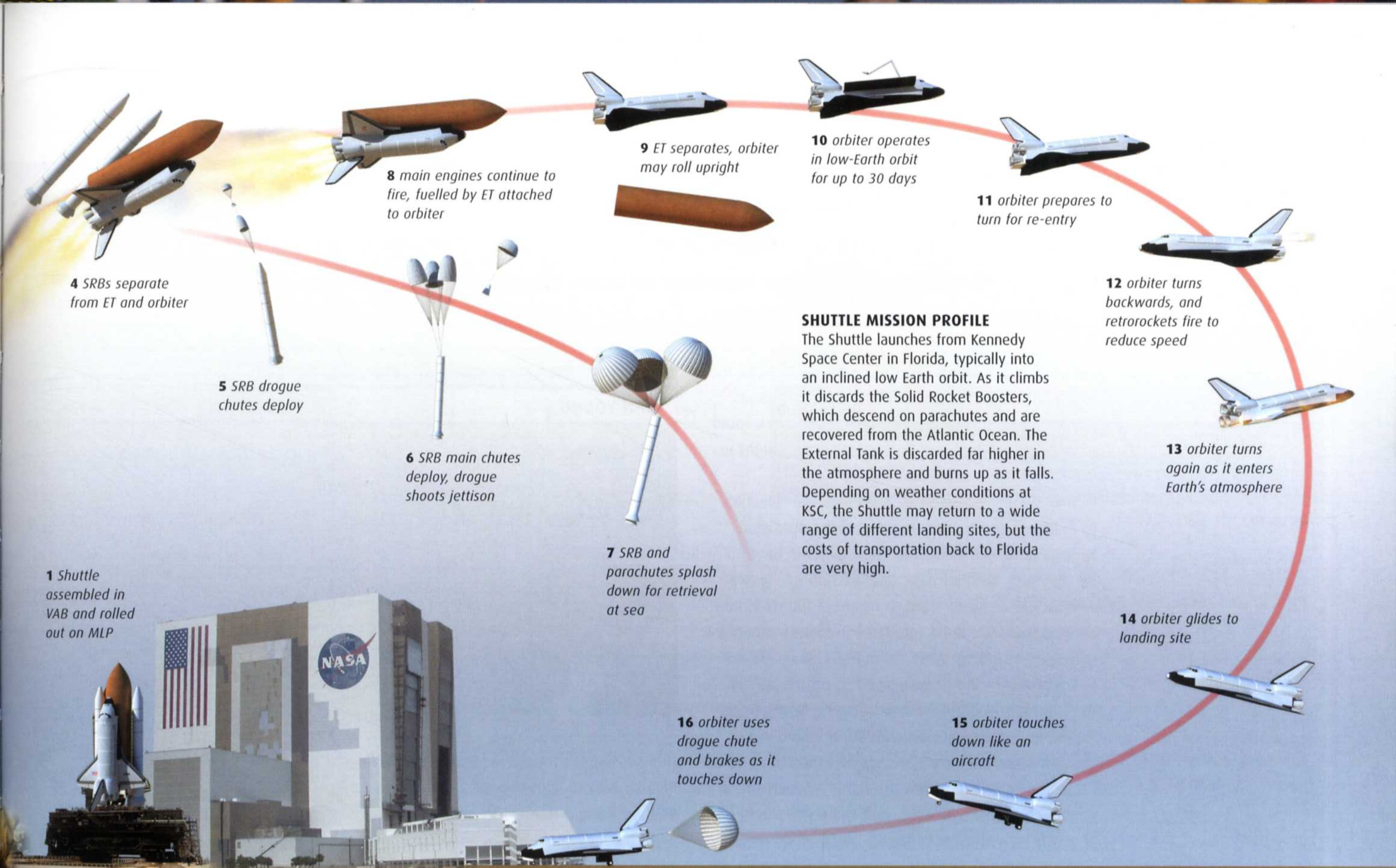
SHUTTLE LAUNCH SYSTEM
During launch, the Space Shuttle Main Engines (SSMEs) draw propellants from the External Tank, and two Solid Rocket Boosters help to get the Shuttle moving. The boosters fall away first, then as the Shuttle nears orbit, it also discards the External Tank.

3 *Shuttle rolls to inverted position*

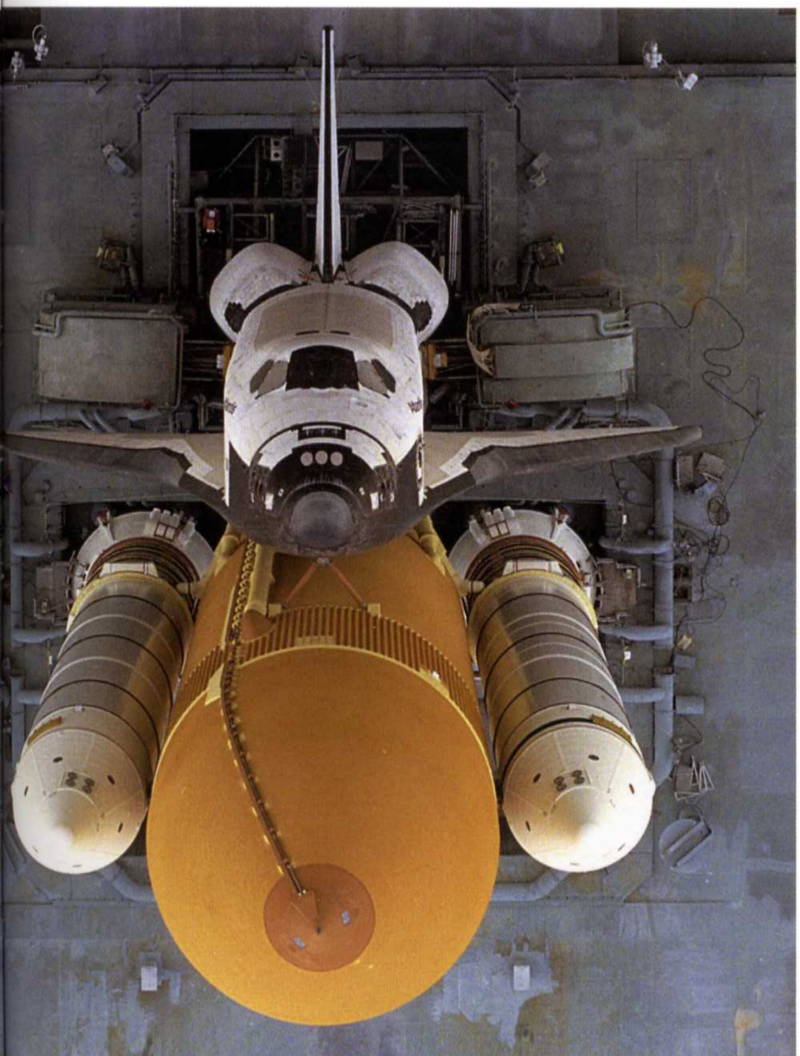
2 *lift-off*



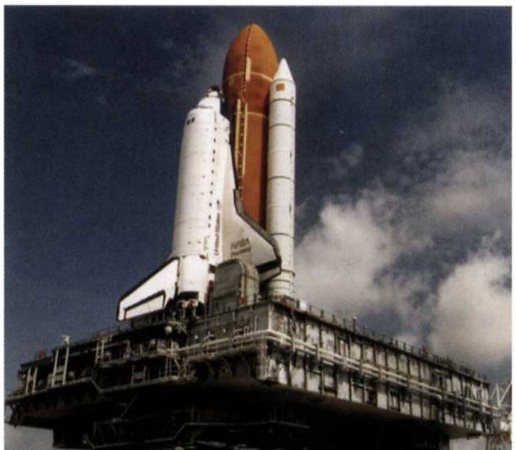
STACKING THE SHUTTLE
The Shuttle system is put together at Kennedy Space Center's Vehicle Assembly Building. The boosters and External Tank are mounted on top of the Mobile Launch Platform (see opposite). The orbiter arrives from its separate processing facility and is hoisted high into the air and lowered into place.



SHUTTLE MISSION PROFILE
The Shuttle launches from Kennedy Space Center in Florida, typically into an inclined low Earth orbit. As it climbs it discards the Solid Rocket Boosters, which descend on parachutes and are recovered from the Atlantic Ocean. The External Tank is discarded far higher in the atmosphere and burns up as it falls. Depending on weather conditions at KSC, the Shuttle may return to a wide range of different landing sites, but the costs of transportation back to Florida are very high.



ATLANTIS STACK ROLL-OUT
A spectacular view from the roof of the Vehicle Assembly Building shows the fully assembled Space Shuttle Atlantis *on top of its Mobile Launch Platform and ready to move to the launch pad.*



CRAWLER TRANSPORTER
The Shuttle is assembled on top of a Mobile Launch Platform (MLP), which is then picked up by a powerful mobile tractor unit for transport to the pad. The entire assembly weighs 8,170 tonnes (18 million lb) and moves at a top speed of 1.6kph (1mph).

FIERY LAUNCH
The pillar of flame on which the whole Shuttle assembly rises into the sky comes largely from the two Solid Rocket Boosters – the exhaust from the Space Shuttle Main Engines is much hotter, blue, and almost transparent.

1981

12 April 1981
Columbia launches from Cape Canaveral on its maiden flight.

14 April 1981
Columbia returns to Edwards Air Force Base, landing on a dry lake bed.

28 April 1981
The Shuttle orbiter returns to Cape Canaveral for processing and repairs.

12 November 1981
Columbia is launched on its second test flight.

14 November 1981
Columbia returns to Earth early, landing again on the lake bed at Edwards.

22 March 1982
Columbia is launched on its third test flight.

30 March 1982
The Shuttle touches down on a reserve strip at White Sands, New Mexico.

27 June 1982
Columbia launches on its final test flight, STS-4.

4 July 1982
Columbia returns to Edwards, landing for the first time on the runway.

Wings into orbit

Developing a spacecraft as complex as the Space Shuttle inevitably took longer than planned, but after a variety of tests, the Shuttle was finally ready for its maiden launch in 1981.

Although NASA was given the go-ahead to build the Space Shuttle in the early 1970s, a host of issues needed to be solved before construction work could even begin, and optimistic hopes of a first flight in 1977 were soon being revised.

One significant cause of delay was the question of military use. In order to provide the predicted savings in launch costs, the Shuttle would have to fly regularly, with perhaps one mission every two weeks. The demand for such frequent flights would only be there if the US totally abandoned unmanned launches, including those for military payloads. For this reason, the Air Force agreed to contribute to development costs – but it extracted a heavy price in return. The entire spacecraft would have to be larger to carry military payloads. It would have to be capable of operating from the USAF's launch site at Vandenberg Air Force Base. And the USAF would be guaranteed a number of launch slots every year.

With all these issues taken into account, work on the prototype Shuttle orbiter, originally to be known as *Constitution*, got under way in June 1974.

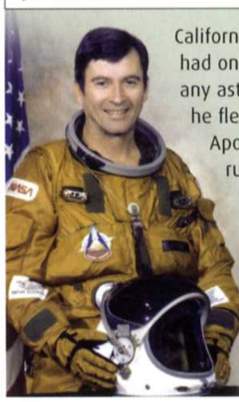
Ready for flight

The Shuttle's complexity made it difficult to test its elements separately. A dummy called *Pathfinder* was built at Marshall Spaceflight Center to test some support systems, scale wind-tunnel models were analyzed at Ames Research Center, and the prototype (now renamed *Enterprise*) was launched from a Boeing 747 in flight tests. But the nature of the orbiter meant there was no way to launch a boilerplate model into space. Similarly, while there were many test firings of the engines, they could not be flown alone. So the first launch of the Space Shuttle became the ultimate "all-up" test – after nine years of development and many billions of dollars of investment, the maiden flight of the fully functional orbiter *Columbia*, designated STS-1, on 12 April 1981, was one of those occasions where a single fault might cause a critical failure, even if everything else worked.

The crucial mission was to be helmed by experienced astronaut John Young (see panel, above), with rookie Bob Crippen at his side. To minimize the risk to their lives, they wore specially designed pressure suits modified from those

BIOGRAPHY

JOHN YOUNG

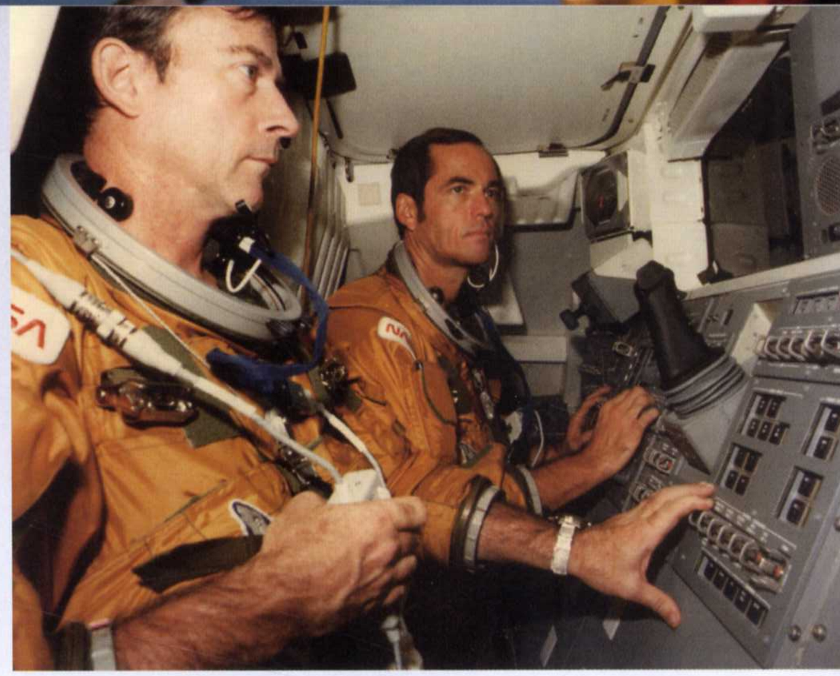


Californian John W. Young (b.1930) had one of the most varied careers of any astronaut. Joining NASA in 1962, he flew on Geminis 3 and 10 and Apollos 10 and 16. Taking over the running of the Astronaut Office from Deke Slayton in 1974, he was in charge of NASA's astronaut selection through to 1987 and commanded STS-1 and STS-9, the first Spacelab mission. He retired from NASA in 2004.

LIFT-OFF!
With its three SSMEs and two SRBs firing simultaneously, Columbia *blasts free of Pad A at Launch Complex 39 on its maiden mission. The date, 12 April 1981, marked the 20th anniversary of Yuri Gagarin's first manned spaceflight.*

GLIDE TESTING
The Shuttle prototype Enterprise *flies free during a test flight in late 1977. Launched from the back of its 747 carrier,* Enterprise *was fitted with instruments to record its flight characteristics at subsonic speeds – there was no way to test the Shuttle's supersonic performance until a real launch.*

MAIDEN FLIGHT
Columbia *arrives for duty at the Kennedy Space Center, Cape Canaveral, piggybacked on a converted 747 carrier aircraft. The aerodynamic tailcone over the Shuttle's main engines reduces turbulence.*



FIRST IMPRESSIONS
John Young (foreground) and Bob Crippen monitor controls on Columbia *during STS-1. On their return to Earth, an enthusiastic Crippen dubbed the Shuttle "a superb flying machine".*

worn by test pilots. As things turned out, the mission went entirely to plan, and the astronauts spent two days giving *Columbia* her orbital shakedown before returning to Earth at Edwards Air Force Base in California.

Despite its overall success, the maiden flight still encountered some problems – most significantly with the Shuttle's thermal tiles (see panel, below), and these were partly responsible for pushing back the date of the second test flight to 12 November 1981. Although STS-2's launch went smoothly and Joe Engle and Dick Truly were able to test the Remote Manipulator System (RMS) for the first time, the planned five-day mission was cut down to just three days due to a problem with *Columbia*'s power-generating fuel cells.

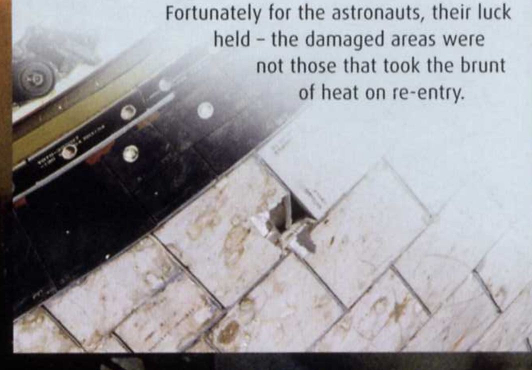
STS-3 launched as planned in March 1982. One of its aims was to study conditions around the Shuttle in space, and to do this the RMS hoisted an instrument pallet out of the cargo bay. The flight was planned to last seven days, but poor weather forced NASA to switch landing sites, and the Shuttle ultimately came back, a day late, to White Sands in New Mexico.

One final test flight was scheduled for June 1982, carrying a classified military cargo. Although a fault with the payload caused problems, the Shuttle itself once again performed well, and after it touched down at Edwards on 4 July, President Reagan announced that the Shuttle was now operational.

TECHNOLOGY

TILE DAMAGE

Throughout the early flights, damage to the Shuttle's fragile ceramic tiles was a recurrent issue. Problems with the delicacy of the tiles themselves, and the adhesive that fixed them to the hull, delayed *Columbia*'s maiden launch, and the Shuttle suffered from lost or damaged tiles on several occasions. Fortunately for the astronauts, their luck held – the damaged areas were not those that took the brunt of heat on re-entry.



Early Shuttle missions

Following the fourth orbital test flight of *Columbia*, President Reagan declared the Space Shuttle operational on 4 July 1982. The shuttle formally entered service with a variety of satellite-related missions.

11 November 1982
Columbia launches on its fifth mission to deploy two commercial communications satellites.

4 April 1983
The second Space Shuttle, *Challenger*, enters service on a mission to launch the first Tracking and Data Relay Satellite.

18 June 1983
Challenger's second flight, sees the launch of two more communications satellites and also rehearses satellite retrieval.

30 August 1983
Challenger launches on her third mission, deploying an Indian communications satellite and carrying out more rehearsals for satellite retrieval operations.

28 November 1983
Columbia launches on the STS-9 mission, carrying the European-built Spacelab module.

3 February 1984
Challenger sets out on the eight-day STS-41B mission, which involves satellite deployments and tests of the MMU.

The fifth flight of *Columbia*, STS-5 in November 1982, was the first to carry a commercial satellite onboard – a mission that was seen as vital to establishing the Shuttle as a commercial launch vehicle. In addition to the flight crew, STS-5 therefore became the first mission to carry "mission specialists" – highly trained non-pilot astronauts. The payload of two communications satellites deployed perfectly, and the only major problem on the mission was a spacesuit flaw that prevented the first spacewalk of the shuttle programme.

Nearly five months later, *Challenger* took to the skies on her maiden flight, STS-6. This mission saw Story Musgrave and Donald Peterson test NASA's new spacesuits on tethered spacewalks, but its main aim was to launch TDRS-A, the first of the Shuttle's Tracking and Data Relay Satellites (see p.201). Deployment was flawless, but a problem in the Inertial Upper Stage (the powerful rocket intended to push the satellite into its final orbit), left it stranded. Controllers on the ground eventually found a way to edge the satellite towards its intended final orbit, but the time this took – coupled with delays to heavy satellite launches while the IUS problem was solved – put the TDRS programme behind schedule.

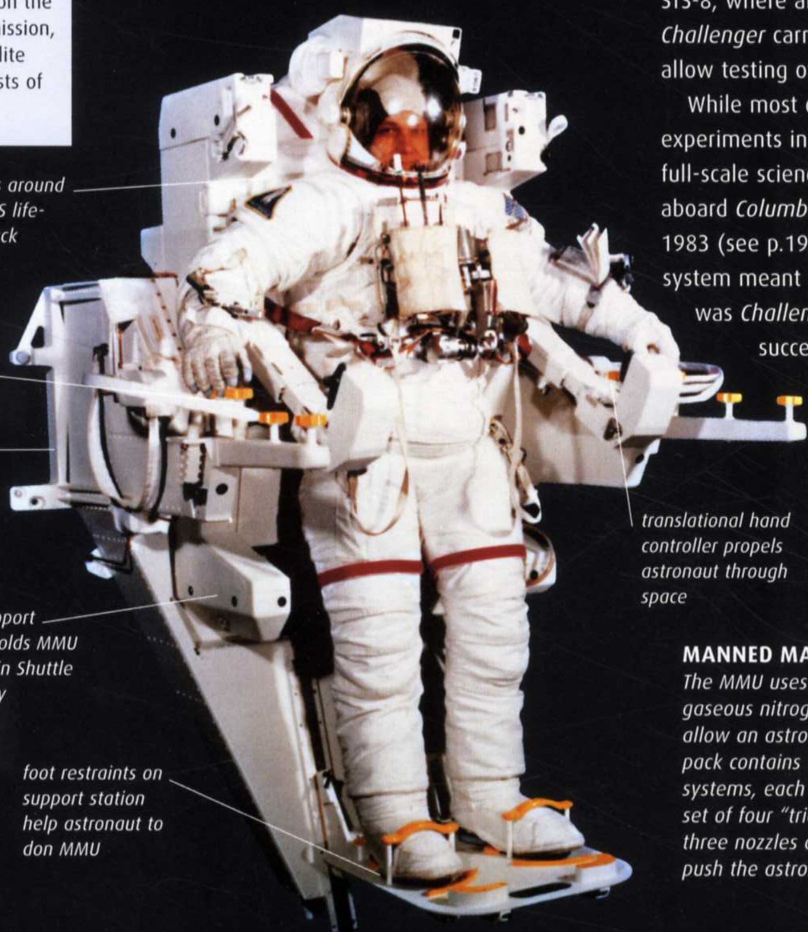
Altered priorities

The mission roster was hurriedly rejigged to work around the TDRS problems, and *Challenger*'s STS-7 flight launched a pair of communications satellites in April. It also released the German-built Shuttle Pallet Applications Satellite (SPAS), a temporary satellite designed to float free of the Shuttle. Recapturing the SPAS at the end of the mission provided experience that would be useful when the shuttle needed to retrieve larger satellites from orbit for servicing (see p.201). The same problems were addressed on the next mission, STS-8, where alongside the Indian satellite Insat-1B, *Challenger* carried a heavyweight dummy satellite to allow testing of the manipulator arm under stress.

While most of these flights carried small-scale experiments in the orbiter's mid-deck, the first full-scale science mission was Spacelab 1, carried aboard *Columbia* for the STS-9 launch in November 1983 (see p.198). A change in the numbering system meant that the tenth Shuttle mission was *Challenger*'s STS-41B. Two satellites were successfully deployed, only for their Payload Assist Modules (smaller, lower-powered equivalents of the IUS) to malfunction. However, the Manned Maneuvering Unit (MMU) was successfully tested, permitting the first untethered spacewalk.

SATELLITE RELEASE
TDRS-A sits atop a pivoting turntable in the Shuttle cargo bay just prior to its release into orbit on Challenger's *STS-6 flight. The problematic IUS rocket stage is shrouded in gold foil beneath the satellite.*

FLYING FREE
Bruce McCandless somersaults above Challenger's *cargo bay during a test of the MMU. In his hands he carries the Trunnion Pin Attachment Device (TPAD), a piece of equipment that, when attached to a satellite, allowed it to be grasped by the Shuttle's robot arm.*



MANNED MANEUVERING UNIT
The MMU uses the controlled release of gaseous nitrogen propellant (GN2) to allow an astronaut to fly free in space. The pack contains two independent propulsion systems, each with its own GN2 tanks and set of four "triad" thrusters (each a set of three nozzles allowing the escaping gas to push the astronaut around three axes).

BIOGRAPHY

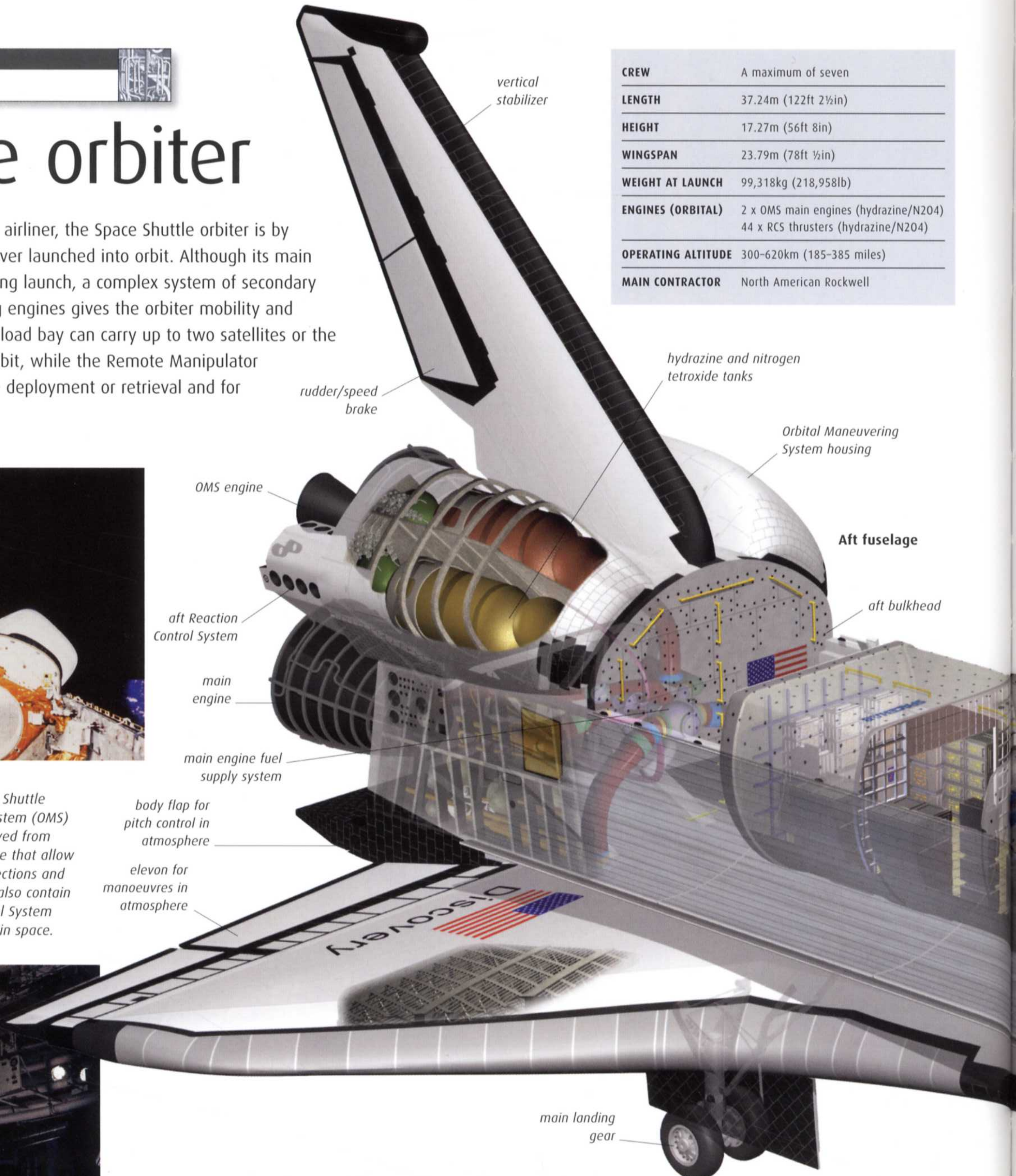
SALLY RIDE

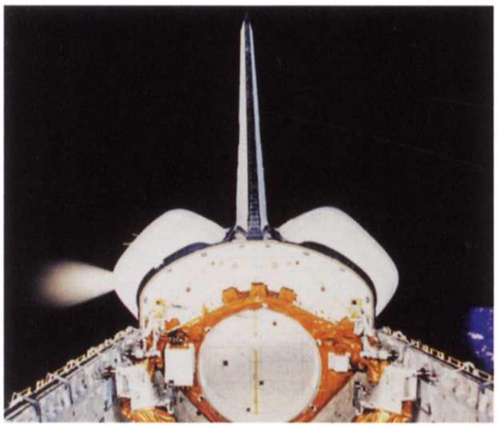
Challenger's STS-7 mission finally put an American woman in space, more than two decades behind the Soviet Union. In 1978, Californian physicist Sally Ride (b.1951) joined NASA in the first astronaut class to accept women. She worked on the Shuttle's robot arm and as Capcom for early Shuttle missions before finally getting a chance to fly.

Shuttle orbiter

The size of a short-haul jet airliner, the Space Shuttle orbiter is by far the largest spacecraft ever launched into orbit. Although its main engines are used only during launch, a complex system of secondary thrusters and manoeuvring engines gives the orbiter mobility and versatility in orbit. The payload bay can carry up to two satellites or the Spacelab laboratory into orbit, while the Remote Manipulator System is used for satellite deployment or retrieval and for orbital construction tasks.

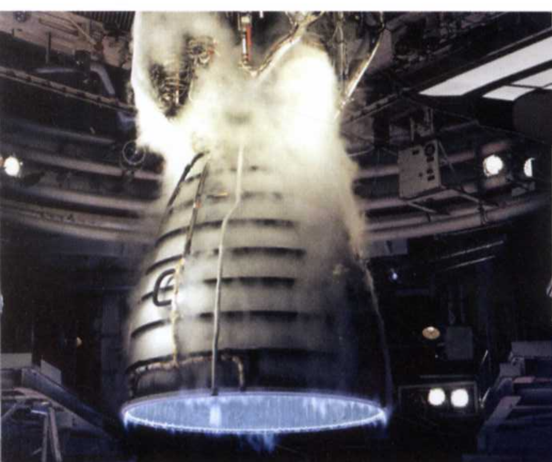
CREW	A maximum of seven
LENGTH	37.24m (122ft 2½in)
HEIGHT	17.27m (56ft 8in)
WINGSPAN	23.79m (78ft ½in)
WEIGHT AT LAUNCH	99,318kg (218,958lb)
ENGINES (ORBITAL)	2 x OMS main engines (hydrazine/N204) 44 x RCS thrusters (hydrazine/N204)
OPERATING ALTITUDE	300–620km (185–385 miles)
MAIN CONTRACTOR	North American Rockwell





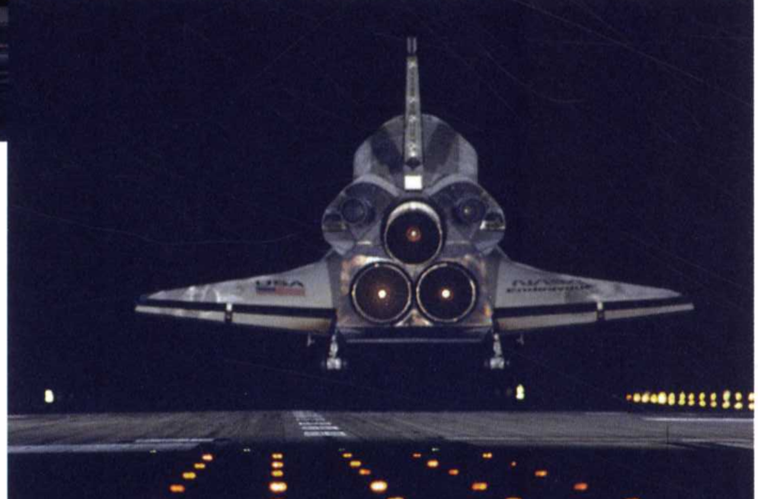
ORBITAL THRUSTERS

The two pods at the back of the Shuttle carry its Orbital Maneuvering System (OMS) engines – a pair of engines derived from the Apollo Service Module engine that allow the Shuttle to make orbital corrections and the retroburn for re-entry. They also contain thrusters for the Reaction Control System (RCS), which orients the Shuttle in space.



SHUTTLE ENGINE TEST

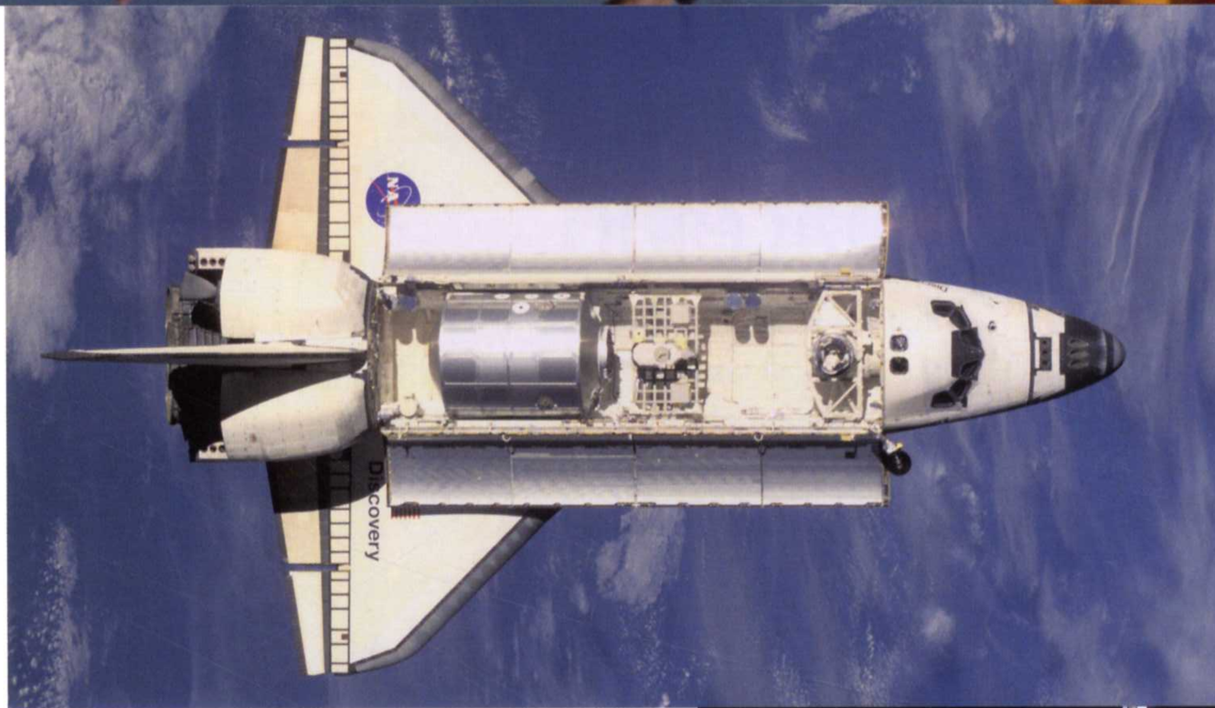
The Space Shuttle Main Engines are extremely complex and are fuelled by high-speed turbopumps that draw propellants from the External Tank. Temperatures in the combustion chamber can reach 3,300°C (6,000°F).

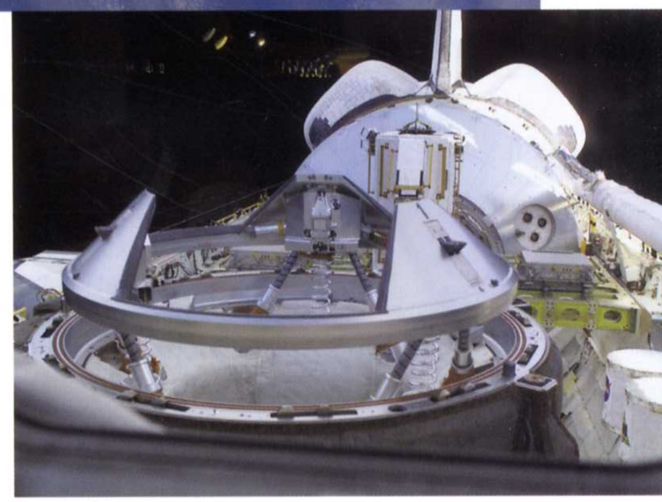


LANDING PROCEDURE

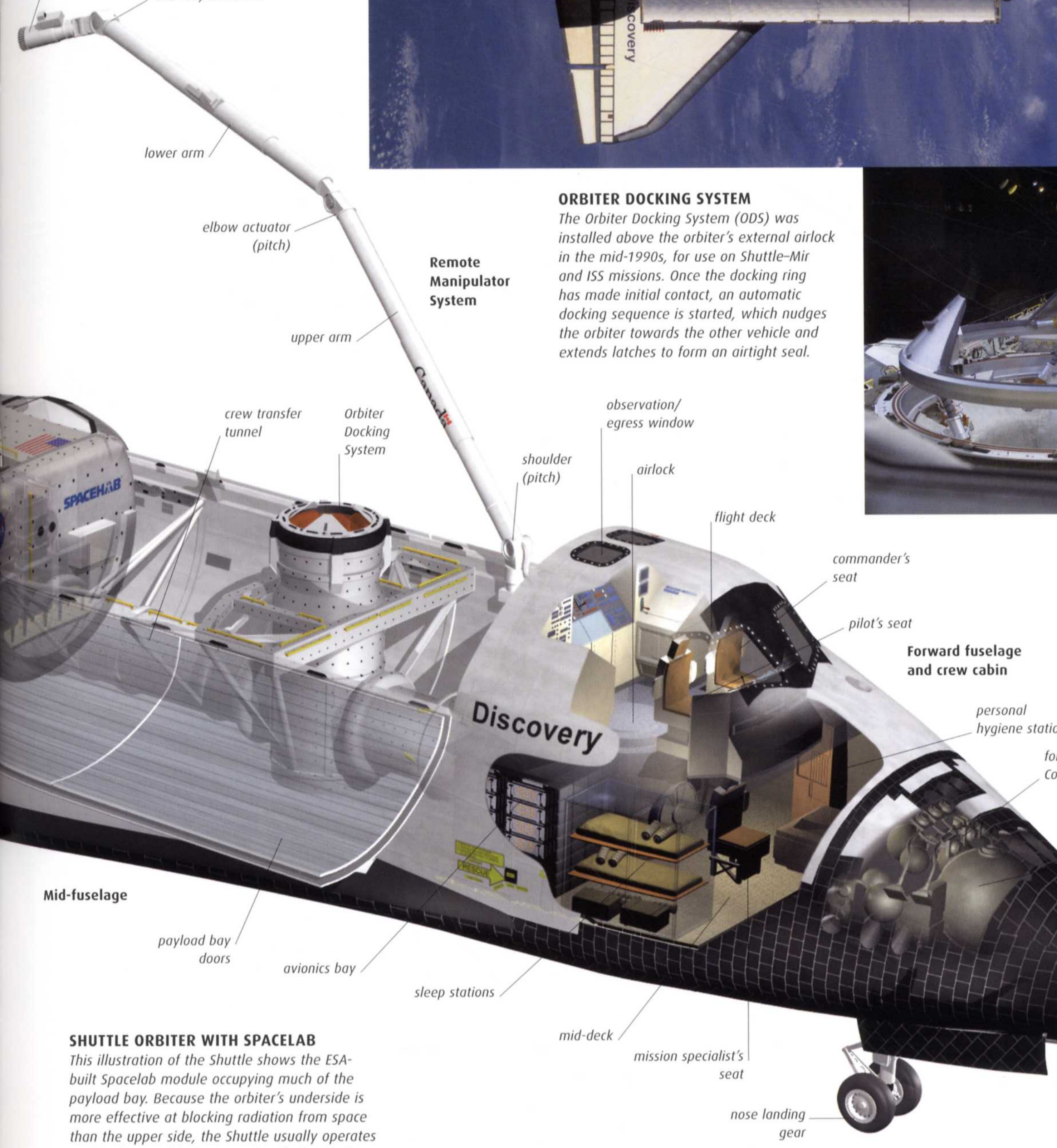
The Shuttle begins its descent by turning backwards in its orbit and using the OMS engines as retro-rockets. It then turns again for re-entry, angling itself so that the heat-resistant ceramic tiles on the underside take the brunt of friction. Once it has slowed to merely supersonic speeds, it is effectively the world's heaviest glider, and gets only one chance at landing. Landing at high speed, it needs a very long runway for its parachute-assisted braking.

THE VIEW FROM ABOVE
The orbiter always opens its payload bay doors after reaching space – their interiors function as radiators that help regulate the spacecraft's temperature. In this photograph from August 2001, Discovery *is approaching the International Space Station, carrying the Italian-built Multi-Purpose Logistics Module – a cargo container for the ISS.*





ORBITER DOCKING SYSTEM
The Orbiter Docking System (ODS) was installed above the orbiter's external airlock in the mid-1990s, for use on Shuttle–Mir and ISS missions. Once the docking ring has made initial contact, an automatic docking sequence is started, which nudges the orbiter towards the other vehicle and extends latches to form an airtight seal.



SHUTTLE ORBITER WITH SPACELAB
This illustration of the Shuttle shows the ESA-built Spacelab module occupying much of the payload bay. Because the orbiter's underside is more effective at blocking radiation from space than the upper side, the Shuttle usually operates upside-down, with the cargo bay facing Earth.

Spacelab

Built by the European Space Agency (ESA) to fit into the Shuttle cargo bay, the Spacelab laboratory module was first flown in 1983 and helped to address NASA's lack of a permanent space station.

28 November 1983
The first Spacelab mission, to test scientific techniques in orbit, begins.

29 April 1985
Spacelab 3 carries a variety of life sciences and microgravity experiments.

29 July 1985
Spacelab 2 carries instruments to study the physics of the Sun.

30 October 1985
Two German scientists and a Dutch ESA astronaut fly on the German-sponsored Spacelab D1.

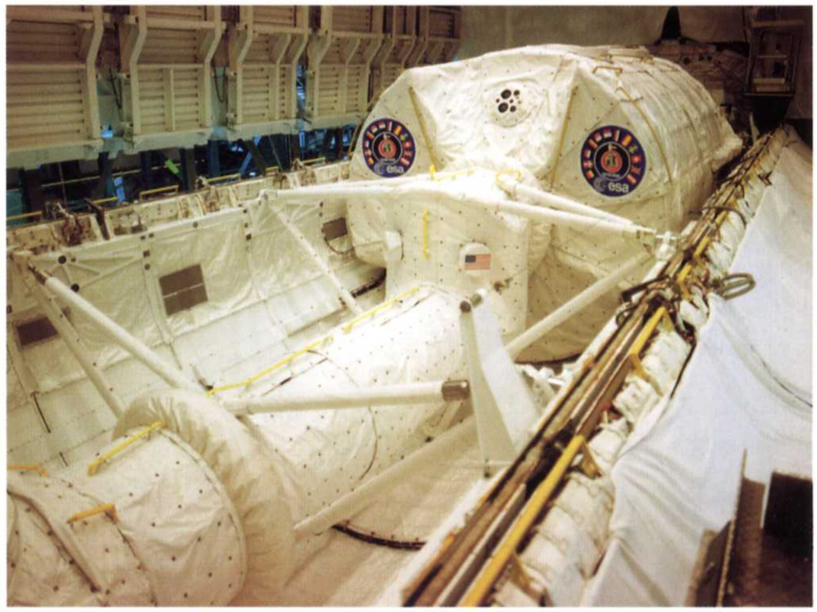
2 December 1990
ASTRO-1 becomes the first astronomy-centred Spacelab mission.

12 September 1992
Spacelab J carries Japanese life-science and microgravity experiments.

27 June 1995
The Shuttle–Mir Spacelab studies the effect of long-duration spaceflight on the Mir astronauts.

1 July 1997
MSL-1R carries specialist materials processing equipment into orbit.

NASA and the foreunner of the ESA, ESRO (see p.228), agreed to develop a laboratory module for the Shuttle's cargo bay in 1973. Europe would provide the module for free, and in exchange their astronauts would fly aboard the Shuttle as payload specialists. STS-9 was scheduled as the first of these international missions, but Spacelab would make heavy use of the TDRS satellite system in order to relay experimental data back to Earth, and so the schedule was put at risk by early problems with the satellites (see p.201). However, once TDRS-A had crawled into its proper orbit and been activated in autumn 1983, the mission was given the go-ahead – the political benefits of taking an international crew aboard the Shuttle outweighed the possible loss of data due to reliance on only one satellite.



SPACELAB INSTALLED
Spacelab and its access tunnel are fitted in Columbia's cargo bay during preparations for the STS-9 mission.

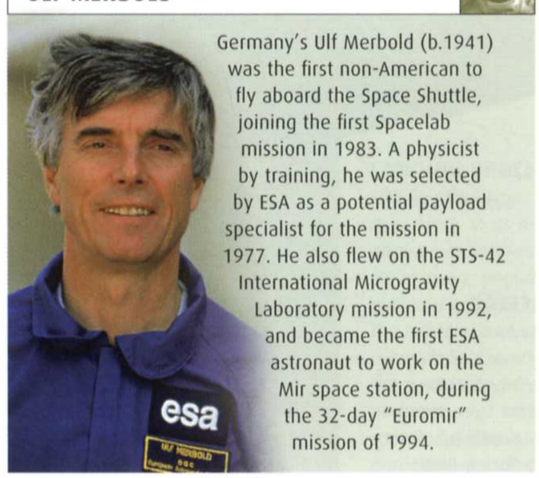
Double success

In the end, Spacelab 1 was a huge success, both politically and scientifically. The laboratory carried a wide range of experiments investigating everything from physics and materials science to space biology and astronomy – its overall aim was to demonstrate the feasibility of carrying out such research in orbit. The six-man crew, including West Germany's Ulf Merbold (see panel, below) worked in groups of three for 12-hour shifts, sending a steady stream of data back to Earth. By the end of the ten-day mission, more scientific data had been returned to Earth than during the entire Skylab programme. Spacelab was built for use in various configurations – as well as the pressurized lab, it had a system of external pallets to carry telescopes and experiments requiring exposure to vacuum. Spacelab modules were flown on 15 more Shuttle missions through to 1998 (NASA had been so impressed with the original European version that it paid ESA to build a second one). Pallets were flown on a further nine missions, up to *Endeavour*'s STS-99 in 2000, which carried a radar that mapped the elevation of 80 per cent of the Earth's surface.

Most later Spacelab missions concentrated on specific areas of science, such as astronomy, life sciences, medicine, geophysics, and materials science. However, science aboard the Shuttle was not confined to Spacelab missions – most flights carried smaller experiments on the orbiter's mid-deck, and other scientific instruments have been flown on the Shuttle outside of the Spacelab programme.

TEMPORARY SATELLITE
Part of the Spacelab system, the Long-Duration Exposure Facility (LDEF) was released into orbit in 1984 and retrieved in 1990.

BIOGRAPHY
ULF MERBOLD

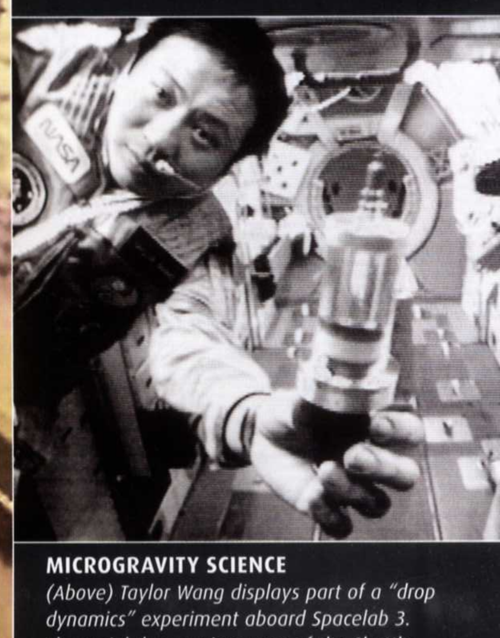


Germany's Ulf Merbold (b.1941) was the first non-American to fly aboard the Space Shuttle, joining the first Spacelab mission in 1983. A physicist by training, he was selected by ESA as a potential payload specialist for the mission in 1977. He also flew on the STS-42 International Microgravity Laboratory mission in 1992, and became the first ESA astronaut to work on the Mir space station, during the 32-day "Euromir" mission of 1994.

BLOOD TESTING
Owen Garriott takes a blood sample from Byron Lichtenberg during the first Spacelab mission. Blood analysis during and after spaceflight reveals that weightlessness affects the production of red blood cells.

MULTITASKING
(Above) Robert Parker (on the left) and Ulf Merbold were able to work on experiments while "wired up" to biometric sensors on Spacelab 1. An ESA experiment, the fluid physics module, can be seen on the left.

LIVE AND DIRECT
(Left) The TDRS satellite network allows huge amounts of experimental data to be sent back from the Shuttle, including near-continuous live television. Here Gregory Linteris (foreground) and Donald Thomas are seen during the MSL-1R Spacelab of 1997.



MICROGRAVITY SCIENCE
(Above) Taylor Wang displays part of a "drop dynamics" experiment aboard Spacelab 3. The weightless environment of the Shuttle allows physicists to see how materials behave away from the influence of gravity.

CAPTURING INTELSAT VI

Retrieving a giant Intelsat comsat during STS-49 required the first ever three-person spacewalk, by (left to right) astronauts Richard Hieb, Tom Akers, and Pierre Thuot. Beyond Akers lies the new motor that would finally boost the satellite to its correct orbit.

Satellite servicing

The arrival of the Space Shuttle made it possible for the first time to retrieve valuable satellites – either repairing them in orbit or returning them to Earth in the cargo bay for more complex refurbishment.

The most eyecatching of the Shuttle's early flights came in April 1984, when *Challenger* launched into an unusually high orbit at the start of the STS-41C mission. After deploying the LDEF satellite (see p.198), the Shuttle's main goal was to rendezvous with a crippled satellite 556km (345 miles) above the Earth and restore it to working order.

The target was the Solar Maximum Mission satellite (SolarMax for short), launched in 1980 to study activity on the Sun but unable to target its instruments thanks to a failure in its control systems. A first attempt to grapple with the satellite, using an MMU piloted by George D. Nelson, failed, and a second try at grabbing SolarMax with the Shuttle's manipulator arm simply sent it into a chaotic spin. The following day, things went better, and the satellite was safely brought into the cargo bay, where it was anchored to a special repair platform. The repairs themselves were lengthy but successful, upgrading the satellite's scientific payload as well as replacing its attitude control system. After two spacewalks, SolarMax was released back into orbit, where it continued to function until it burned up on re-entry to the Earth's atmosphere in 1989.

Chasing satellites

The next repair mission was a case of tidying up unfinished business – rescuing the pair of mis-deployed satellites released during the STS-41B mission in February 1984 (see p.194). Both had fallen far short of their intended orbits after their Payload Assist Modules (PAMs) had failed. After a brief pause in commercial launches while the problem was sorted out, the maiden flight of *Discovery* in August had flawlessly deployed another pair of communications satellites. With the PAM problem apparently resolved, *Discovery*'s second mission, STS-51A, in November 1984, was to retrieve the stranded satellites for a refit on the ground. A difficult mission, requiring the chase-down and capture of two separate satelllites, was made harder still by the lack of grips on the satellites – unlike SolarMax, they had not been built with in-flight servicing in mind.

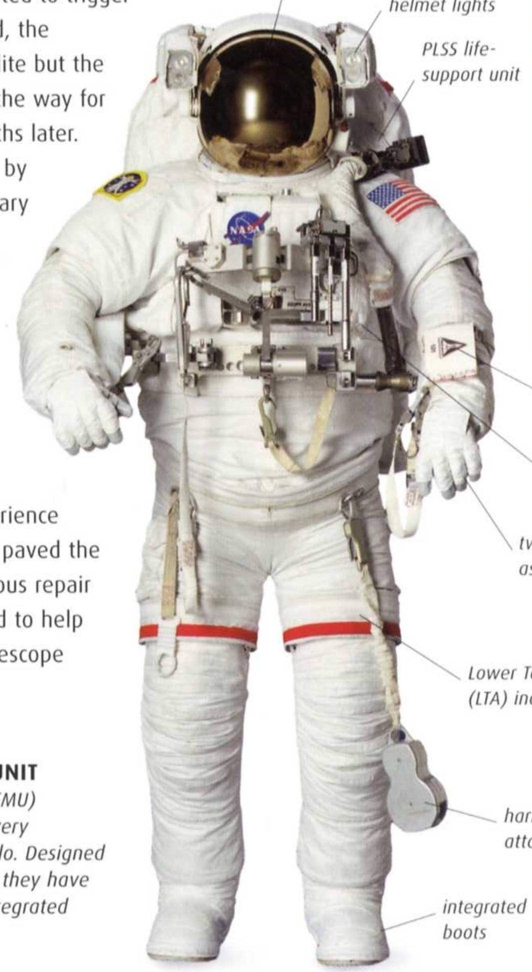
The STS-51D mission offered a great demonstration of the Shuttle's flexibility. In April 1985, *Discovery* released a US Navy Leasat communications satellite from the cargo bay, only to see it spin away without power as a switch intended to trigger its built-in kick motor failed to activate. Rather than abandon the satellite, the mission was extended – the satellite was chased down, and a spacewalk was improvised in which the astronauts attempted to trigger the switch manually. In the end, the switch failed to wake the satellite but the astronauts' assessment paved the way for repair by *Discovery* a few months later.

Following the hiatus caused by the *Challenger* disaster in January 1986 (see p.202) it was some time before NASA attempted any further satellite repairs (see p.207). When it came, however, it was truly spectacular, as *Endeavour* caught up with and retrieved the enormous Intelsat VI communications satellite. Experience in handling this giant in space paved the way for the even more ambitious repair missions that would be needed to help maintain the Hubble Space Telescope (see pp.252–53).

TECHNOLOGY

THE TDRS SATELLITE SYSTEM

Situated 35,786km (22,240 miles) above the Earth's equator, NASA's Tracking and Data Relay Satellites orbit the Earth once each day, acting as relay stations for data from faster-orbiting satellites and spacecraft closer to Earth. Seen from Earth, each TDRS remains stationary in the sky – a fixed platform through which data can be sent and received from satellites at lower altitude. Moving a small antenna on a vehicle such as the Space Shuttle in order to track each TDRS is far easier than tracking the Shuttle from the ground as it speeds across the sky.



EXTRAVEHICULAR MOBILITY UNIT

The Extravehicular Mobility Unit (EMU) spacesuits of the Shuttle era are very different from those used on Apollo. Designed for work in weightless conditions, they have a hard upper torso unit and an integrated PLSS backpack.

3 February 1984
Two communications satellites deployed from *Challenger* fail to reach their intended orbit after a rocket motor failure.

8 April 1984
Challenger captures and repairs the SolarMax satellite – the first ever satellite maintenance in orbit.

13–15 November 1984
Discovery retrieves the Westar-VI and Palapa B-2 satelllites, deployed by *Challenger* in February, for a refit back on Earth.

16 April 1985
Discovery chases down and attempts to repair the faulty Leasat-3 communications satellite launched earlier in this STS-51D mission.

31 August 1985
Discovery's STS-51I mission successfully recaptures and "hotwires" the Leasat-3 satellite.

13 May 1992
Endeavour captures and repairs the 4.2-tonne Intelsat VI satellite as part of the STS-49 mission.

2 December 1993
Endeavour is launched on the first of several servicing missions to the Hubble Space Telescope.

FATAL LIFTOFF
Cameras at pad 39-B photographed Challenger *on its way to catastrophe. Residue from the SRB fuel formed a temporary seal over the cracked O-ring, delaying the disaster.*

"Reality must take precedence over public relations, for **nature cannot be fooled**."

Richard Feynman's appendix to the Rogers Report, 1987

BIOGRAPHY

CHRISTA MCAULIFFE

NASA set up its Teacher in Space project in 1984, in an attempt to reignite public interest in space. Out of 11,500 applicants, Christa McAuliffe (1948–86), a Social Studies teacher at Concord High School, New Hampshire, was chosen for her inspirational teaching style. She began training in autumn 1985 and was welcomed to the team of the doomed STS-51L, dying with her six crewmates on 28 January 1986. In 2004, NASA began a new "educator astronaut" programme, and McAuliffe's original backup, Barbara Morgan, is now due to fly aboard STS-118.

The *Challenger* disaster

By the end of 1985, the Space Shuttle programme finally seemed to be getting into gear, with shorter intervals between flights and faster turnaround times for individual spacecraft – but then disaster struck.

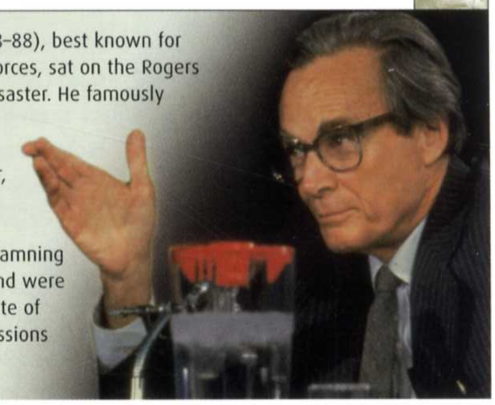
BLOWTORCH EFFECT
Fifty-eight seconds after launch, ground-based cameras capture a superheated jet of flame emerging from a joint on Challenger's *right SRB, burning through the vulnerable support strut.*

The launch of *Challenger*'s STS-51L mission on 28 January 1986 was the focus of unusual attention. It was the 25th flight, a minor landmark in itself, and was also carrying a notable passenger – Christa McAuliffe, from New Hampshire, had been selected to become the first teacher in space and would be delivering lessons over a live television link from the Shuttle to schools across the country.

But just 73 seconds after launch, both NASA and the general public were left reeling as *Challenger* exploded in mid-flight, instantly killing all seven astronauts onboard, showering debris across the Atlantic Ocean, and fatally undermining America's dreams of routine manned spaceflight.

BIOGRAPHY

RICHARD FEYNMAN



Physicist Richard P. Feynman (1918–88), best known for his work on fundamental atomic forces, sat on the Rogers Commission into the *Challenger* disaster. He famously revealed the vulnerability of the SRB O-rings by dipping a sample of material into a jug of iced water, then snapping it with his hands. Feynman's conclusions about the Shuttle's safety were even more damning than those of the official report, and were added as an appendix – his estimate of one failure in roughly every 50 missions was to prove tragically accurate.

Accident investigation

Future Shuttle flights were immediately grounded while an investigation got under way. Television pictures soon revealed the direct cause of the accident – a jet of scalding flame emerging from the side of one of the SRBs and burning through one of the struts that held it to the rest of the launch assembly. As the strut gave way, the SRB had swung round, slamming into the external tank and rupturing it in a huge explosion that completely destroyed the spacecraft, instantly killing the crew.

Tracing the accident back to its origins, however, took longer. President Reagan appointed an investigation board, which included Neil Armstrong and Richard Feynman (see panel, above). They tracked the jet of flame back to a crack in one of the joints between sections of the right SRB – the night before launch, frost had formed on the Shuttle, and a rubber O-ring seal had become brittle and unable to fill the joint properly under the stress of launch.

However, the investigation did not stop there – it comprehensively tore apart NASA's managerial structure, attacking a culture of complacency in which the concerns of several engineers about the launch had become lost in bureaucracy and never reached the ears of key safety managers.

Although there was probably nothing that could have saved *Challenger*'s crew in this exact chain of events, the board also recommended extensive changes to Shuttle hardware that would keep the spaceplane grounded for a total of 32 months. *Challenger* would be replaced – NASA had enough "spare parts" to put together a new Shuttle, *Endeavour*. But a more conservative launch policy would result in far longer turnaround times – putting an end to the optimistic estimates of launch rates on which the entire Shuttle concept was founded.

GHOST OF THE CULPRIT
Search teams recovered 40 fragments of Challenger's *SRBs, including a joint from the right-hand side that retained traces of O-ring seal tracks.*

ENTOMBMENT
Following the investigation, the recovered Challenger *wreckage was buried in empty missile silos on Canaveral Air Force Station.*

22 January 1986
STS-51L is scheduled for an afternoon launch but is delayed.

24 January 1986
More delays are caused by poor weather at an emergency landing site in Senegal. The abort site is moved to Casablanca, but this runway cannot handle a night landing, so the launch is moved to local morning. Later, poor weather forecasts at Cape Canaveral put the launch back still further.

27 January 1986
High winds force another delay. Forecasts of cold weather for next morning prompt engineers at SRB maker Morton Thiokol to call a teleconference with NASA managers regarding a possible problem with the O-rings. In the end, Thiokol's own management overrule the engineers and recommend that the launch should proceed.

28 January 1986
Challenger launches at 11:38 EST.

EXPERIENCE

THE CHALLENGER DISASTER

"Go at throttle up"

For those on the ground or watching the televised launch coverage, the explosion that destroyed *Challenger* came without warning. But the decision to launch had hung in the balance almost until the last moment.

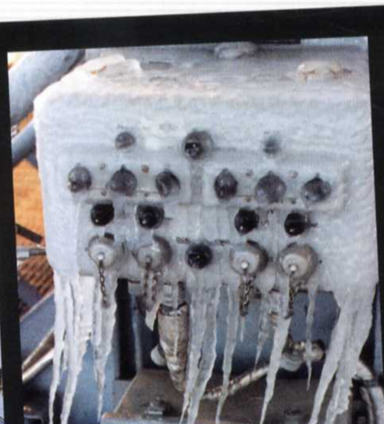
THE CREW
Photographed following a launch rehearsal on 8 January, Challenger's crew (left to right: McAuliffe, Jarvis, Resnik, Scobee, McNair, Smith, and Onizuka) pose in the White Room next to the Shuttle hatch.

On the morning of 28 January 1986, the crew of *Challenger* prepared for the launch from Cape Canaveral. Out on Pad 39B, the ice team had been working through the night to tackle frost forming on the Fixed Service Structure supporting *Challenger*. After a week of delays, there was an eagerness to get under way, although Rockwell, the Shuttle's main contractor, was now expressing concerns about launch safety. A hardware failure led to a two-hour delay, during which Program Manager Arnold Aldrich agreed to a further ice inspection at 10:30, but the engineers' worries about the O-rings had not reached him, and when the ice appeared to be melting, he gave the go-ahead. The Shuttle launched at 11:38 EST, but a minute later disaster struck:

Dick Scobee: Point nine.
Michael Smith: There's Mach one.
DS: Going through nineteen thousand. Okay we're throttling down. Throttling up.
MS: Throttle up.
DS: Roger.
MS: Feel that mother go.
DS: Woooohoooo.
MS: Thirty-five thousand going through one point five.
DS: Reading four eighty six on mine.
MS: Yep, that's what I've got, too.
DS: Roger, go at throttle up.
MS: Uhoh [The line then goes dead].

SHOCK IN THE CROWD
At first, spectators watching from the Launch Complex 39 Observation Gantry were unsure of the explosion's meaning – those who had never seen a Shuttle launch before had been told that SRB separation could be spectacular, and it took several moments to realize something had gone badly wrong.

COUNTDOWN TO DISASTER
The Challenger *crew had spent four months in training for their STS 51-L mission, but on the morning of 28 January, long icicles had formed on the Shuttle's service structure. Debate about the effects of the ice continued even as the crew made their way to the Shuttle, and the final decision to go ahead came just 20 minutes before launch.*



"One minute, fifteen seconds… Velocity twenty-nine hundred feet per second. **Altitude nine nautical miles.** Downrange distance seven nautical miles … Obviously a **major malfunction."**

NASA launch commentary, 28 January 1986

From the ground, no one saw the puffs of smoke that emerged from an O-ring seal on the right-hand SRB. Within two and a half seconds of ignition, they had disappeared anyway, as the expanding SRB casing temporarily closed the gap formed by the cracked O-ring. It was not until 59 seconds into the flight that flame suddenly spurted from the joint, growing rapidly into a white-hot blowtorch that was blown backwards onto the central tank and the SRB's own support strut. At 72 seconds, the strut gave way, and a second later, the external tank ruptured, its exposed propellants exploding in a blast that tore the *Challenger* orbiter to pieces, killing all on board.

STATE OF MOURNING
President Ronald Reagan had been due to give his State of the Union address to the nation on the night of 28 January. Instead, he delivered a moving address to a shocked and grieving nation.

"We mourn seven heroes: **Michael Smith, Dick Scobee, Judith Resnik, Ronald McNair, Ellison Onizuka, Gregory Jarvis, and Christa McAuliffe** … The crew of the Space Shuttle Challenger honoured us by the manner in which they lived their lives. **We will never forget them** nor the last time we saw them this morning, as they prepared for their journey and waved goodbye and 'slipped the surly bonds of Earth' to 'touch the face of God'."

President Ronald Reagan, 28 January 1986

MISSION CONTROL
Staff at Johnson Space Center in Houston watch in stunned disbelief as their communications and telemetry disappear and the television monitors reveal the awful reason why (main picture).

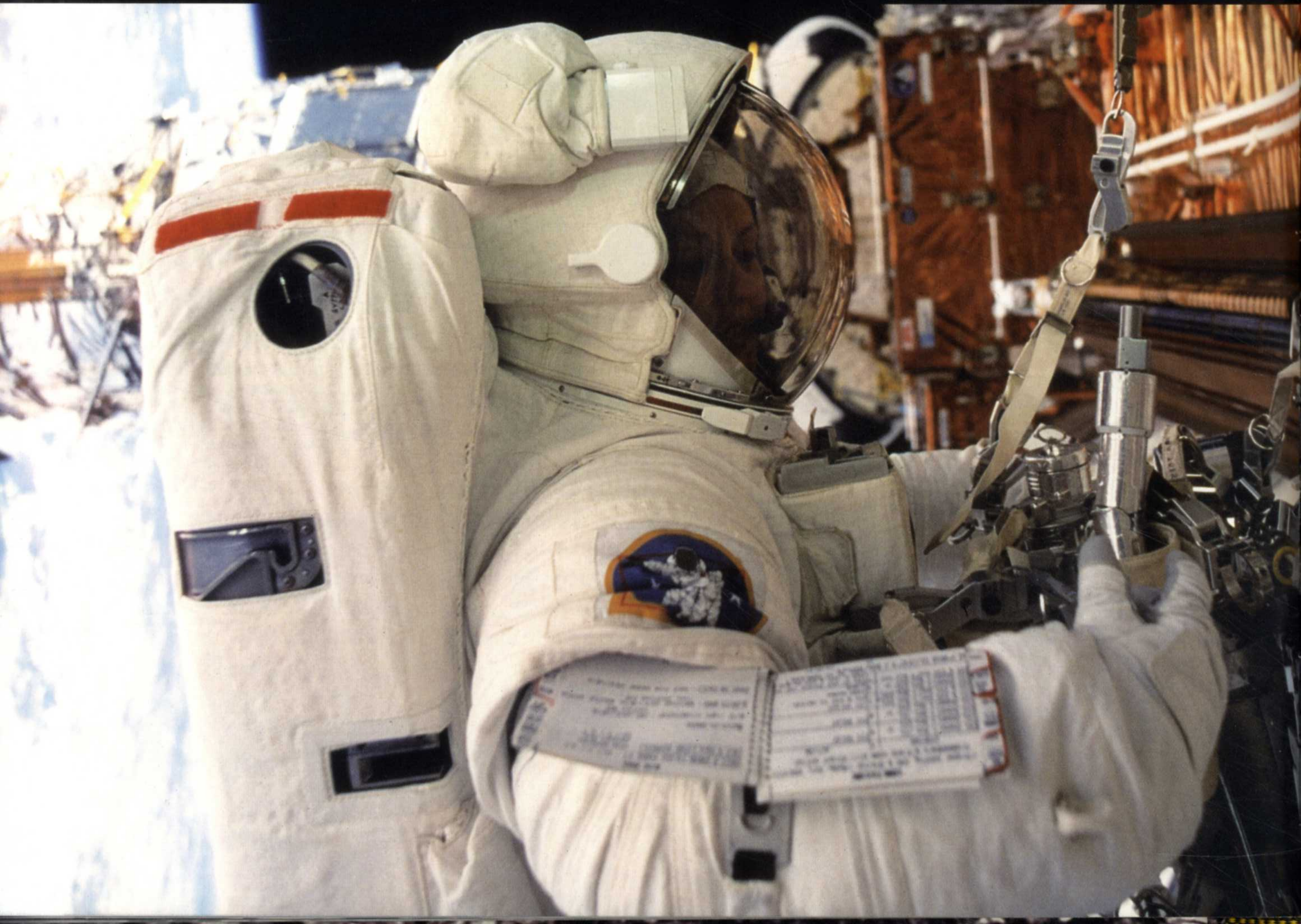
RETRIEVAL OF LDEF
During the STS-32 mission of January 1990, Columbia *retrieved an experiment called the Long Duration Exposure Facility, which had been released by* Challenger *back in 1984.*

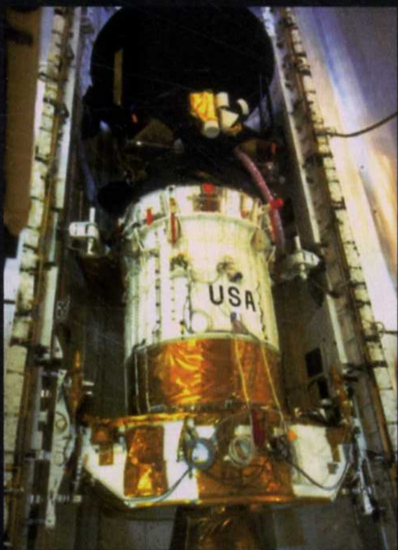
After *Challenger*

The Space Shuttle's return-to-flight programme began falteringly, but within a couple of years, the Shuttle and its crews were accomplishing some of its most ambitious missions yet.

When *Discovery* returned to space in late September 1988, the eyes of the world were watching what would otherwise have been a relatively mundane mission. As well as testing the modified hardware, NASA was using the flight to finally continue its deployment of the TDRS data satellite network. TDRS-C would supplement the earlier TDRS-A, which was now beginning to fail. Over the next two years, the Shuttle would launch a further three satellites, improving and reinforcing its orbital communications.

Many of the other Shuttle missions in this period were launches of classified, defence-related satellites. With the Shuttle grounded for so long, the US military had been without a heavy-lift launch vehicle (the USAF's own Titan IV was not yet ready), and they did not hesitate to demand their share of launch slots. Aside from a couple of commercial satellite launches, other significant missions of the time included much-delayed spaceprobe launches (of the Galileo, Magellan, and Ulysses probes) and deployment of the Hubble Space Telescope (HST), delayed since 1986 and finally launched in April 1990. Spacelab missions resumed in 1990 with the ASTRO-1 astronomy mission. Throughout 1991, the rate of missions gradually ramped up again, and some limited spacewalking took place in the cargo bay.





DEPLOYING GALILEO
The post-Challenger hiatus meant that when this Jupiter probe was finally deployed, it had missed its best launch window and had to take a circuitous route to the giant planet.

HITCHING A LIFT
Astronaut Story Musgrave rides to the top of the HST aboard Endeavour's robot arm, preparing to fit covers to some instruments during the last of STS-61's five spacewalks. Jeffrey Hoffman works below him in the payload bay.

Endeavour debuts

Challenger's replacement, *Endeavour*, finally took to the skies in May 1992 with the STS-49 mission. Its aim was the most ambitious satellite repair yet attempted – servicing an enormous Intelsat communications satellite that had been stranded when the upper stage of its Titan rocket failed back in 1990. The successful mission provided valuable experience that helped in planning an even more ambitious mission to the Hubble Space Telescope in 1993 (see panel, right).

Throughout the early 1990s, NASA's four Shuttles carried out a successful and varied series of missions. Satellite and spaceprobe deployments continued, along with the release and retrieval of short-term independent satellites, or free fliers, developed with the European and Japanese space agencies. There were also further Spacelab missions – the experiments carried in the mid-deck storage lockers inside the spacecraft were supplemented by the commercially built Spacehab module, which fitted behind the main cabin while leaving most of the cargo bay empty, and contained additional experiment lockers for paying customers.

Alongside a programme of joint missions with the Russian space station Mir (see p.217), a number of missions of the early and mid-1990s also developed techniques for construction of the International Space Station (ISS). Spacewalking astronauts practised building structures that might be used in a space station, including long truss sections and frameworks (see p.186). There were even opportunities to test rather more speculative ideas – *Atlantis* carried an experimental trolley-car for astronaut transport in its cargo bay in April 1991, while two other missions unwound a tethered satellite that generated electricity as its 1km- (⅔-mile-) long tether sliced through the Earth's magnetic field.

REPLACING HUBBLE'S SOLAR PANELS
Mission specialist Kathryn Thornton fixes replacement solar arrays to the Hubble Space Telescope during STS-61. Spacewalk activities are listed in the checklist on her right cuff.

29 September 1988
Discovery launches on the first Space Shuttle mission since 1986. A decision to simplify the mission codes sees *Discovery*'s flight named STS-26. However, schedule delays will frequently lead to later missions launching out of order.

4 May 1989
Atlantis deploys the Venus-bound Magellan spaceprobe.

18 October 1989
Atlantis launches the Galileo probe to Jupiter.

25 April 1990
Discovery deploys the Hubble Space Telescope.

6 October 1990
The Ulysses solar probe is launched from *Discovery*.

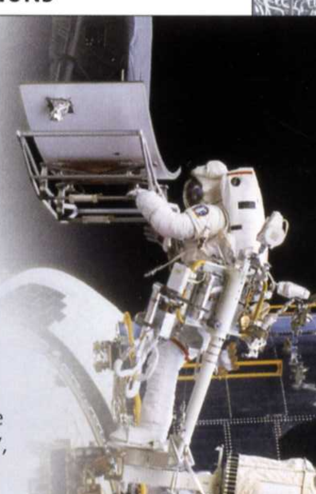
21 June 1993
Endeavour's STS-57 is the first mission to carry the Spacehab experimental module.

2 December 1993
Endeavour launches on its epic STS-61 mission to repair the HST.

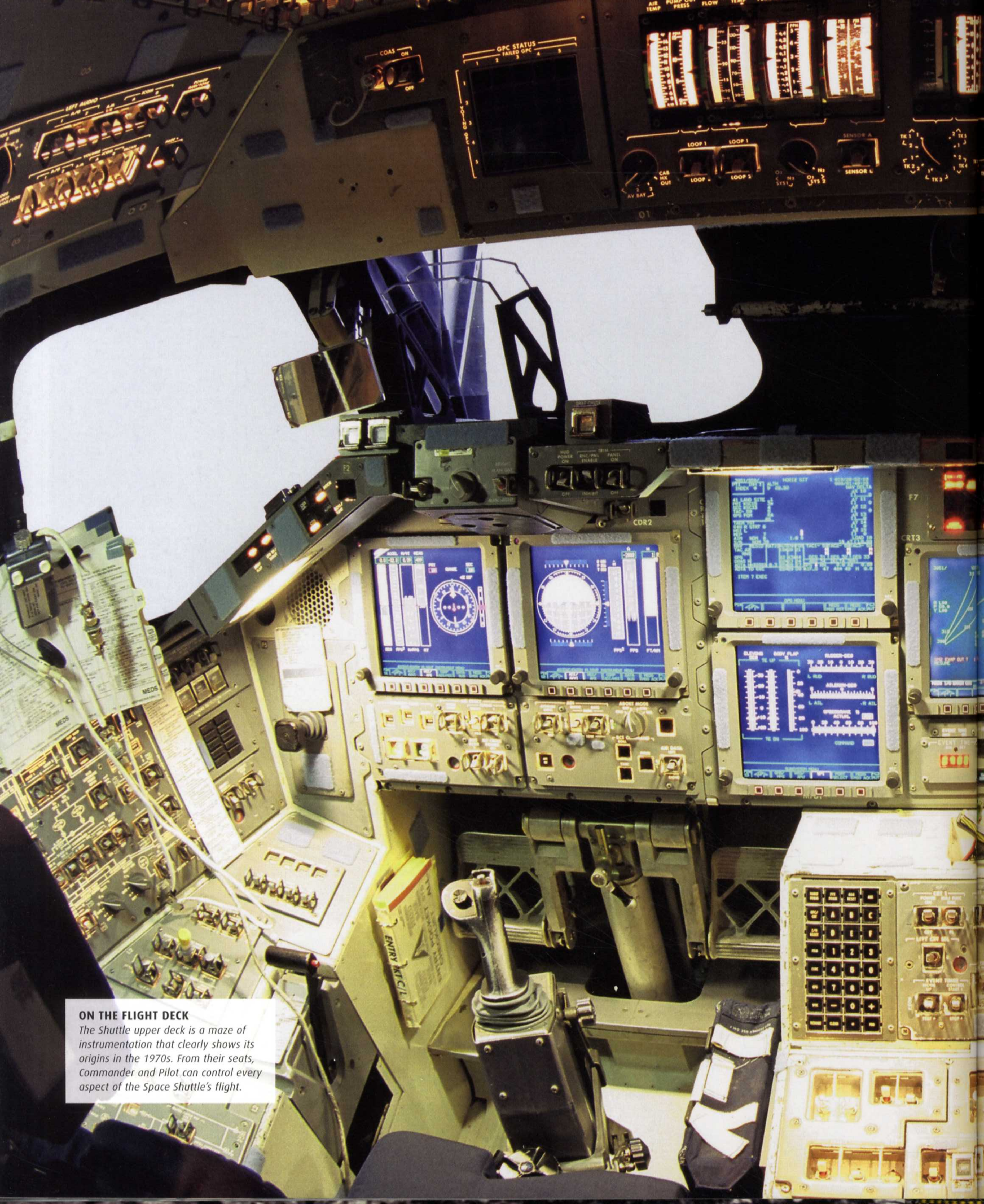
3 February 1995
The launch of *Discovery* on STS-63 marks the beginning of the Shuttle–Mir programme.

TECHNOLOGY

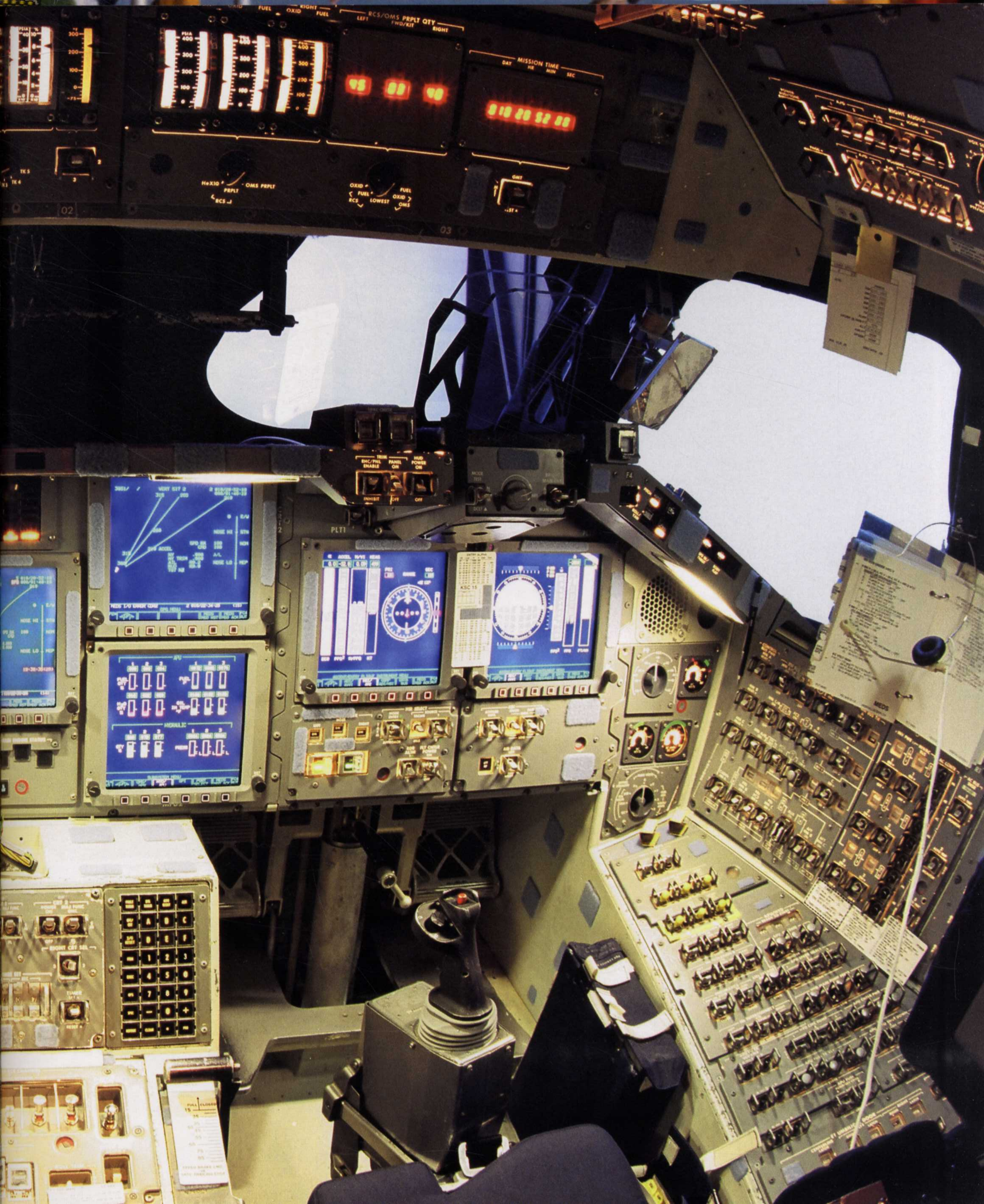
HUBBLE SPACE TELESCOPE REPAIR MISSIONS



Shortly after the Hubble Space Telescope's much-delayed deployment, NASA was highly embarrassed at the discovery that its great orbital observatory was delivering out-of-focus images (see p.252) – a major flaw in the mirror design had not been spotted before launch, and the telescope was crippled. Fortunately, the HST was designed with orbital servicing in mind – and each of its major instruments could be removed and replaced with relative ease. Engineers on the ground soon devised a system of corrective optics that could fit into one of the instrument bays and bring Hubble's vision into focus for the remaining instruments. The capture and repair of the HST by *Endeavour* in 1993 ultimately took five spacewalks, but it resurrected the HST. Further maintenance missions took place in 1997, 1999, and 2002, and a final one is planned for 2008.



ON THE FLIGHT DECK
The Shuttle upper deck is a maze of instrumentation that clearly shows its origins in the 1970s. From their seats, Commander and Pilot can control every aspect of the Space Shuttle's flight.


RCS/OMS PRPLT QTY
LEFT
FWD/KIT
RIGHT
MISSION TIME
DAY HR MIN SEC
HeXIO
OMS PRPLT
PRPLT
RCS
OXID
FUEL
LOWEST
OMS
GMT
TRIM
RHC/PNL ENABLE
PANEL ON
HUD POWER ON
INHIBIT
OFF
PLT1
F4
KSC 15
MEDS

The Mir space station

Less than a month after the American space programme had suffered the loss of *Challenger*, the Soviet Union launched what turned out to be its last great space project – the space station Mir.

19 February 1986
The empty Mir core module is launched from Baikonur Cosmodrome into an orbit 390km (242 miles) above the Earth.

13 March 1986
The first crew of two cosmonauts is launched on an 18-week mission to both Mir and Salyut 7.

5 February 1987
After a seven-month hiatus caused by delays to Kvant-1, Mir's second crew is launched aboard Soyuz-TM 2.

9 April 1987
Kvant-1 docks with Mir.

22 July 1987
Soyuz-TM 3 brings a crew including Mohammad Faris, the first Syrian astronaut, to Mir. During the visit, the first in-orbit crew exchange is made.

21 December 1988
Cosmonauts Musa Manarov and Vladimir Titov return to Earth after spending 366 days in orbit.

6 December 1989
Kvant-2 is added to the Mir core.

10 June 1990
The Kristall materials science module docks with Mir.

Development work on a more complex modular space station – one that would have more than two docking points, allowing the attachment of extra individual elements to the basic core – began in the mid-1970s. The station's design and construction was undertaken at NPO Energia (the former OKB-1) under Valentin Glushko, and initially it was supposed to use only the relatively lightweight, Soyuz-derived elements of the bureau's own Salyut stations. But the cancellation of Vladimir Chelomei's military Almaz programme (see p.179) led to a decision that the station should also accommodate much heavier modules developed from Chelomei's TKS space ferry. Development progressed throughout the early 1980s but was sidetracked by the pressure of other spacecraft programmes, such as the Progress cargo ferry (see panel, right) and Buran (see p.214). It only took priority once the bureau was given a launch deadline of spring 1986 – to coincide with the 27th Communist Party Congress.

Building in orbit

A lot of information about Mir (the name means "peace" and also "world") was available from the start – part of the new Soviet leader Mikhail Gorbachev's policy of *glasnost*, or "openness". The nature of the station was revealed within a few weeks of its launch – scientific equipment would be added piece by piece in additional modules, keeping the core of the space station comparatively uncrowded. This was just as well, since Mir was intended to be the first space station with more-or-less continuous occupancy. Once the first crew got Mir up and running on 13 March, they then travelled to the abandoned Salyut 7, revived it from deep-frozen slumber, and ultimately transferred a large amount of experimental material to the new station.

The second major element of Mir, the Kvant-1 astrophysics module, docked with the station just over a year later. Originally designed for Salyut 7, Kvant-1 also contained Mir's first set of gyrodynes – electronically controlled stabilizing wheels that allowed the station's attitude to be altered in orbit without wasting valuable thruster fuel.

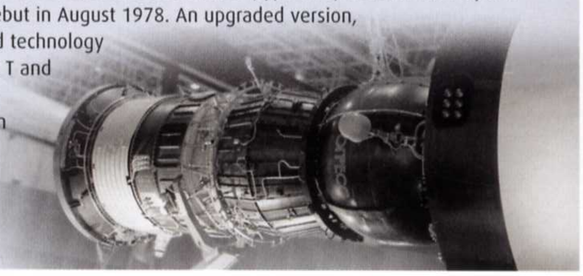
In late 1989, Kvant-2 brought an improved life-support system. In the meantime, various crews had come and gone – in December 1988, Vladimir Titov and Musa Manarov had become the first people to spend a year in space and had recovered well. Mir's multiple ports allowed two spacecraft to be docked at the same time, so a new crew could arrive without the old one having to leave. Because Soyuz could carry three people and Mir had a typical crew of two, foreign "guest cosmonauts" could also visit, even if an entire crew was being replaced at the same time.

Kristall, a materials science and geophysics laboratory, was added to the station in June 1990 – but by the time Mir expanded further, the Soviet Union would have slipped into history.

TECHNOLOGY

THE PROGRESS CARGO SPACECRAFT

In order to keep a crew in orbit for long periods of time, a new type of spacecraft was needed – an automated supply vehicle that could fly to orbit, rendezvous, and dock with a space station almost automatically. This was the purpose of the Progress ferry. The original Progress evolved from Soyuz manned ferries (type 7K-T) used in the Salyut 6 mission and made its debut in August 1978. An upgraded version, Progress M, incorporated technology developed for the Soyuz T and was first used in August 1989. This newer version could also transport a capsule capable of returning to Earth with samples from Mir.

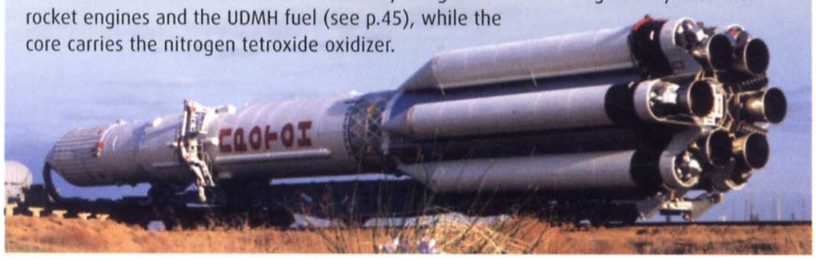


RUSH HOUR IN ORBIT
By late 1990, Mir was in an upside-down T-shaped configuration. Kvant-1 is mounted above the core module at the end of Mir's long axis, while Kvant-2 and Kristall form the cross-bar of the "T".

TECHNOLOGY

THE PROTON LAUNCH VEHICLE

All of Mir's major components were launched with the Soviet Union's most reliable heavy launch vehicle, the Proton. Formally known as the UR-500, the Proton got its name from a series of heavy satellites that it launched early in its career, which began in 1965 and continues today. The rocket was designed for launching the Almaz station and various lunar missions, and was a rival to Korolev's ambitious N1. Despite appearances, the "boosters" around the base are actually integral to the first stage – they hold the rocket engines and the UDMH fuel (see p.45), while the core carries the nitrogen tetroxide oxidizer.



FIRST CREW
Leonid Kizim (left) and Vladimir Solovyov were chosen for the Mir–Salyut mission because they had already spent a long tour of duty aboard Salyut 7.

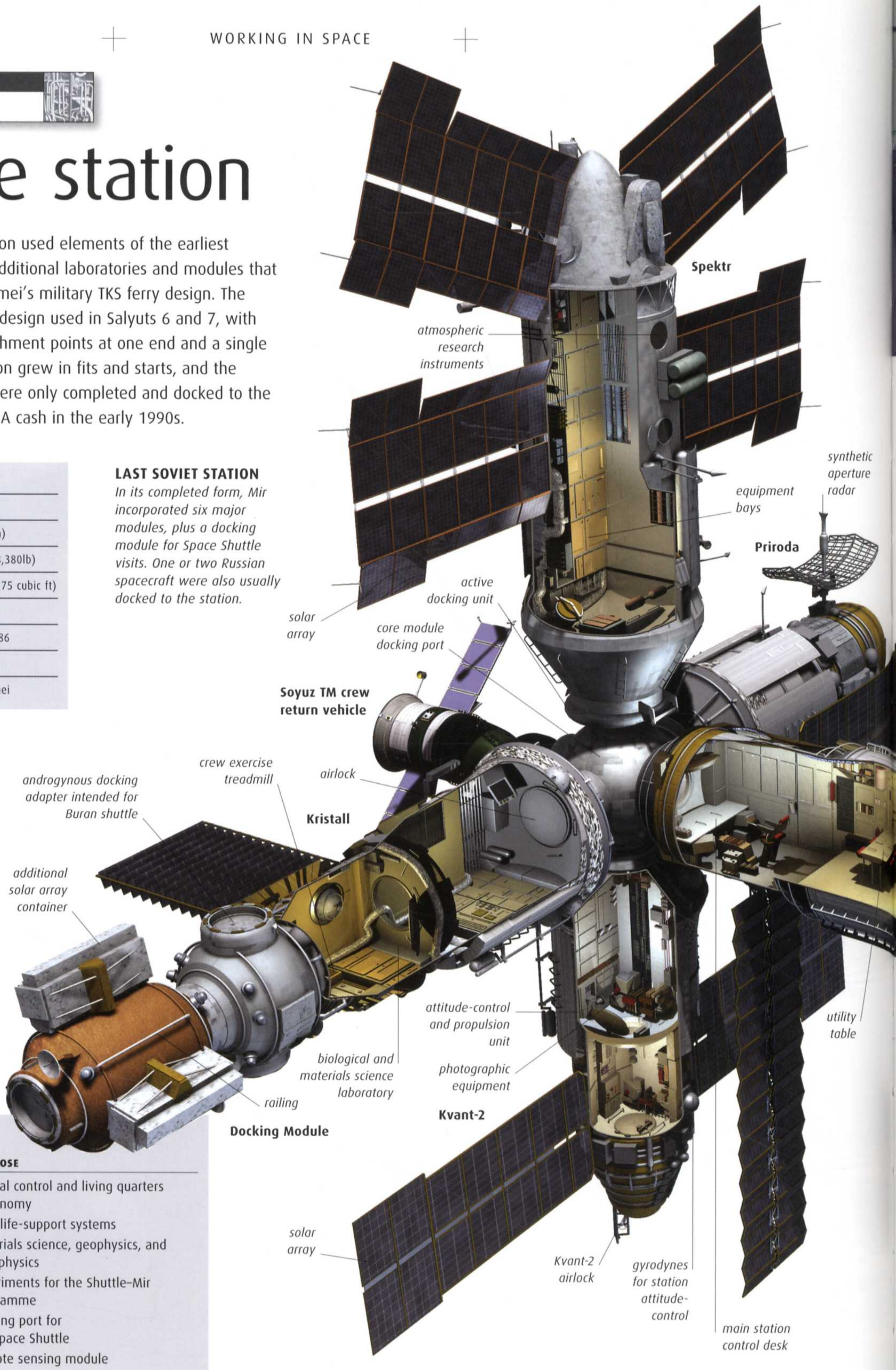
TECHNOLOGY

MODULAR SOVIET SPACE STATION

Mir space station

The world's first modular space station used elements of the earliest civilian (DOS) Salyut stations, with additional laboratories and modules that were often based on Vladimir Chelomei's military TKS ferry design. The core module was based on the DOS design used in Salyuts 6 and 7, with a docking module offering five attachment points at one end and a single docking point at the other. The station grew in fits and starts, and the final modules, Spektr and Priroda, were only completed and docked to the station following an injection of NASA cash in the early 1990s.

CREW	3
LENGTH	32.9m (108ft)
MAXIMUM DIAMETER	4.35m (14ft 3in)
TOTAL MASS	117,205kg (258,380lb)
HABITABLE VOLUME (CORE)	90 cubic m (3,175 cubic ft)
NUMBER OF DOCKING PORTS	2
DATE OF LAUNCH	19 February 1986
DATE OF RE-ENTRY	23 March 2001
MAIN CONTRACTOR	Energia/Chelomei



LAST SOVIET STATION
In its completed form, Mir incorporated six major modules, plus a docking module for Space Shuttle visits. One or two Russian spacecraft were also usually docked to the station.

KRISTALL AT KRUNICHEV
Although Mir was designed by the Energia bureau (formerly OKB-1), some of its modules, such as Kristall, were built at the Krunichev factory in Moscow.

CONSTRUCTION HISTORY

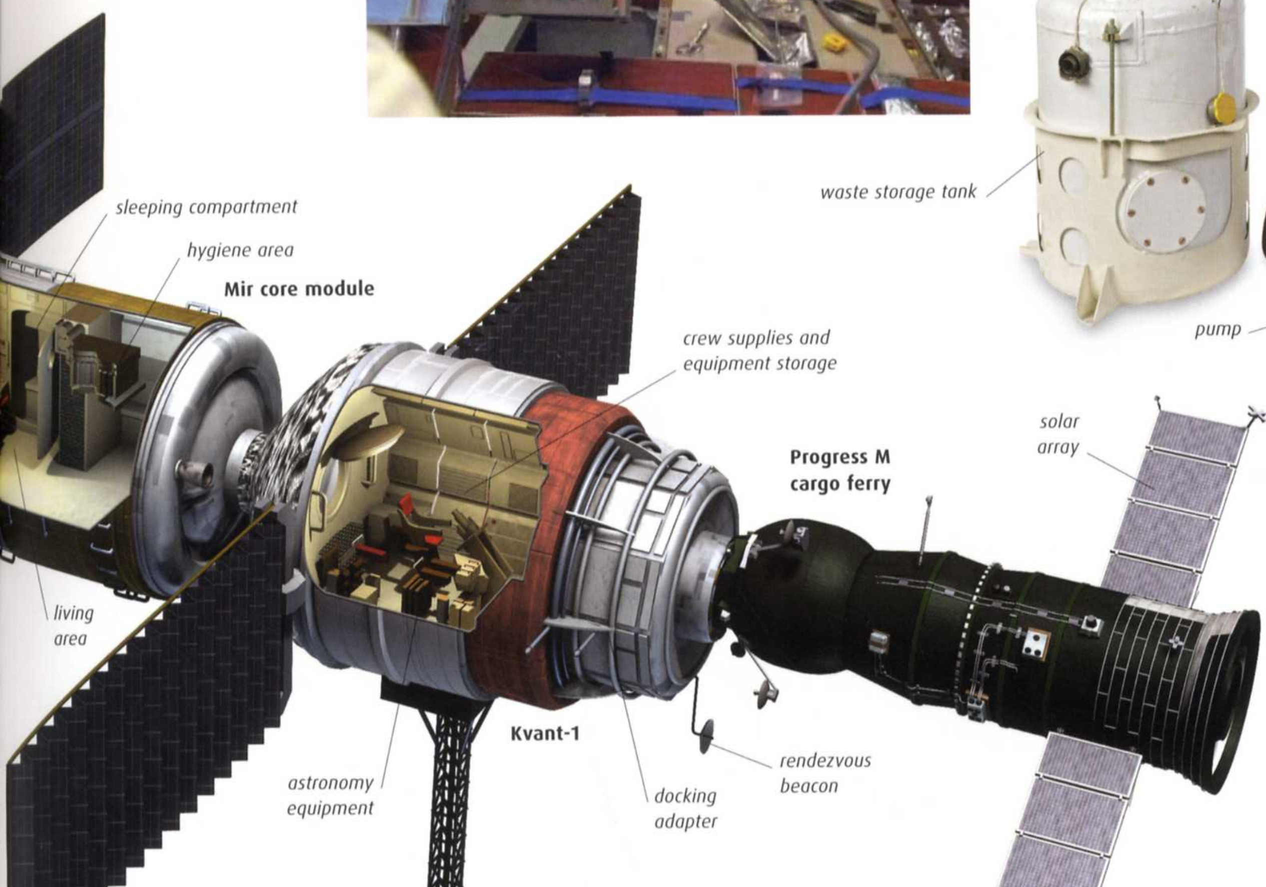
MODULE	DOCKING DATE	PURPOSE
Core	n/a	Central control and living quarters
Kvant-1	April 1987	Astronomy
Kvant-2	December 1989	New life-support systems
Kristall	June 1990	Materials science, geophysics, and astrophysics
Spektr	June 1995	Experiments for the Shuttle–Mir programme
Docking Module	November 1995	Docking port for the Space Shuttle
Priroda	April 1996	Remote sensing module

MIR CORE MODULE
The core module contained living quarters and the station's main control console. Designed for use in weightless conditions, handles run along the walls and hatches are high up on the bulkheads. The unseen ceiling has exercise equipment attached. Cosmonauts could secure themselves to the chairs by folding their feet back under the seats.

INSIDE THE CONNECTING NODE
Valeri Korzun negotiates air-conditioning hoses snaking their way through the main connecting node, which linked the core module to five other areas of the station.

MIR IN USE
After a decade of use, the station's interior was a jumble of cables, experiments, and the ephemera of everyday life. However, the cosmonauts were still careful to make sure that floating objects were secured onto surfaces.

SPACE TOILET
Cosmonauts travelling to and from Mir had to rely on some basic toilet facilities aboard their Soyuz taxis.



TIMEKEEPERS
Although the station had an orbital period of around 90 minutes, and so saw 16 sunrises every day, a normal daily rhythm was maintained with the help of onboard clocks.

SPACE STATION TOOLS
A variety of different tools were devised for the Mir astronauts to use either inside or outside the station. Frequent spacewalks (EVAs) were used to service the station or install scientific experiments in open space.

Buran – the Soviet shuttle

The Soviet Union's attempt to match NASA with a partially reusable spaceplane system pushed the country's space programme to the limit and ultimately foundered under pressure from technical difficulties and a faltering economy.

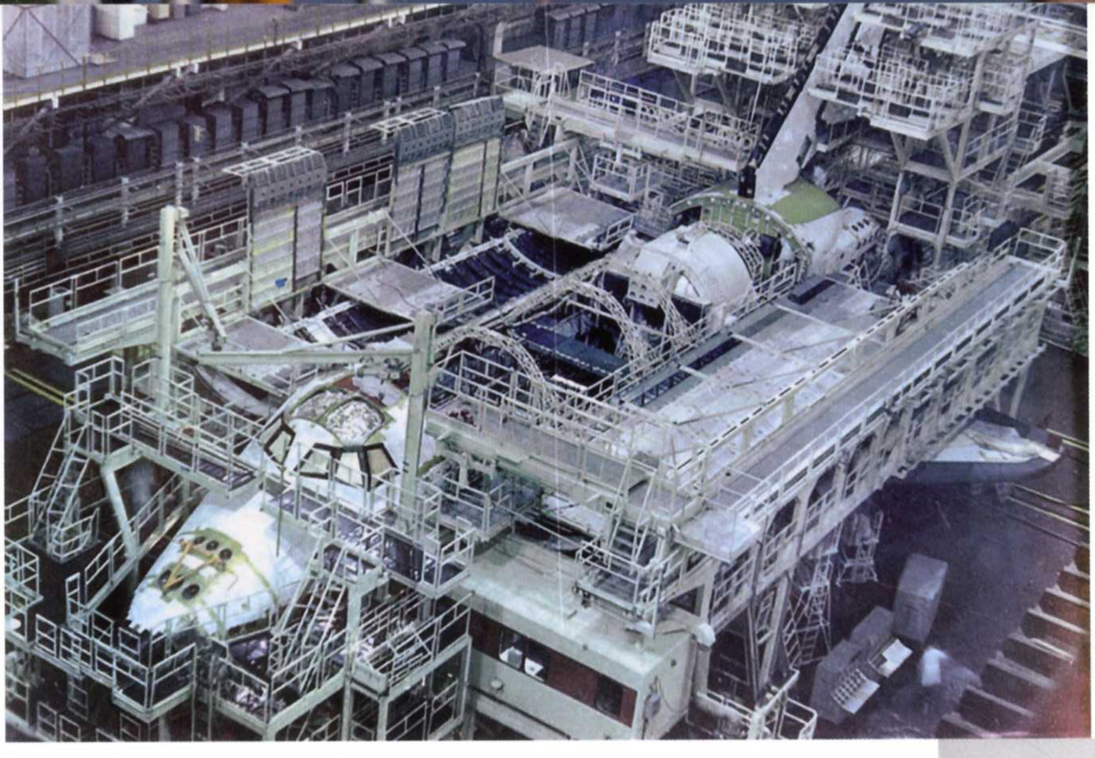
With hindsight, the decision to develop a Soviet equivalent to NASA's Space Shuttle was a disastrous mistake – some have even suggested that the project's crippling development costs helped push the entire Soviet economy over the edge, ultimately leading to the country's collapse.

Of course, when the decision was announced in 1974, it seemed quite logical – NASA's Shuttle, partly financed by the US Air Force, was expected to play a key strategic role in the military exploitation of space, and naturally the Soviets felt they had to have a similar system to maintain parity – even if the exact applications for it remained uncertain.

Design issues

Development of this major new programme, known as the Reusable Space System (MKS in its Russian acronym) was entrusted to NPO Energia. While the spacecraft itself ended up looking strikingly similar

ON THE PAD
Buran awaits its maiden flight in the Kazakh desert. The orbiter's resemblance to the US Space Shuttle is obvious, but the rest of the assembly – the long Energia rocket with its four boosters – is unique.



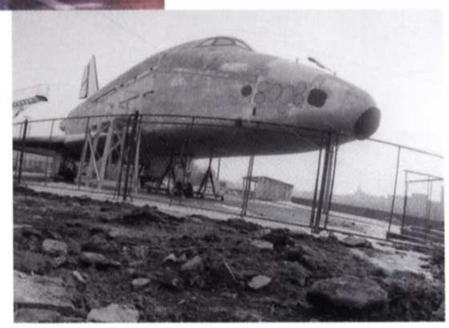
UNDER CONSTRUCTION
The MKS orbiters were mainly built at the NPO Energia factory in Kaliningrad, near Moscow (shown here). They were then flown to Baikonur Cosmodrome piggybacked on a converted Antonov An-225 aircraft.

to its US rival, its operating principle and launch hardware were quite different. Rather than build large solid rocket boosters, of which they had no experience, the design team soon settled on the idea of a new, entirely liquid-fuelled, rocket system, ultimately called the Energia (see panel, below).

The MKS orbiter itself, usually known as Buran ("snowstorm") after the first of three ultimately built, was externally an almost exact twin of the Space Shuttle. Although the Soviet designers tried to come up with an alternative look, wind tunnel tests soon revealed that NASA had done its job well and the Shuttle was already the best shape for the job. The main difference between the two vehicles was that the Buran orbiter did not carry main engines inside its body, relying instead on the Energia launcher's own powerful engines. This made the system more wasteful than NASA's, but it potentially allowed Buran to carry an extra five tonnes of payload compared to the Shuttle and also meant that the Energia could function as an independent launcher, carrying payloads other than the orbiter.

Brief career

As with the Shuttle a variety of more or less complex dummy orbiters were built during MKS development, some of which were used in glide tests. However, the real Buran orbiter flew just once, on 15 November 1988. Like other Soviet spacecraft, the entire system had been designed for automatic as well as piloted flight, and Buran's first and only mission was controlled entirely from the ground. The flight lasted 206 minutes, during which the spacecraft orbited the Earth twice and executed a perfect landing. The system had proven itself – but too late. By now, the Soviet system was in its death throes, and the programme was suspended as a cost-cutting measure. Two half-finished orbiters were left in limbo while Buran was reduced to touring air shows as a display of ingenious Soviet technology. By the time the programme was formally cancelled in 1993, the country and system that produced it were themselves things of the past.



SAD END
After the project's cancellation, the Buran orbiter remained stuck in Kazakhstan, sheltered in a deteriorating hangar at Tyuratam. In May 2002, the roof of the hangar collapsed, destroying Buran and its Energia launcher and killing eight people.

APPROACH AND LANDING
Buran glides towards the landing strip under automatic control at the end of its first flight around the Earth. Longer automatic flights should have followed over the next few years, before manned flights in the mid-1990s.

1 August 1974
Valentin Glushko, head of the newly merged NPO Energia design bureau, orders work to begin on a new heavy-lift launcher and a reusable orbiter spacecraft.

12 February 1976
Work on the MKS system is formally approved by the Soviet government.

1 January 1986
Constant delays lead to an extensive shake-up in the Buran project's management.

15 May 1987
The first launch of the Energia rocket puts a Polyus military satellite into space, though it is classed as a failure when a guidance problem prevents the Polyus reaching its proper orbit.

29 October 1988
A first attempt at launching Buran is aborted 51 seconds before launch due to a software fault.

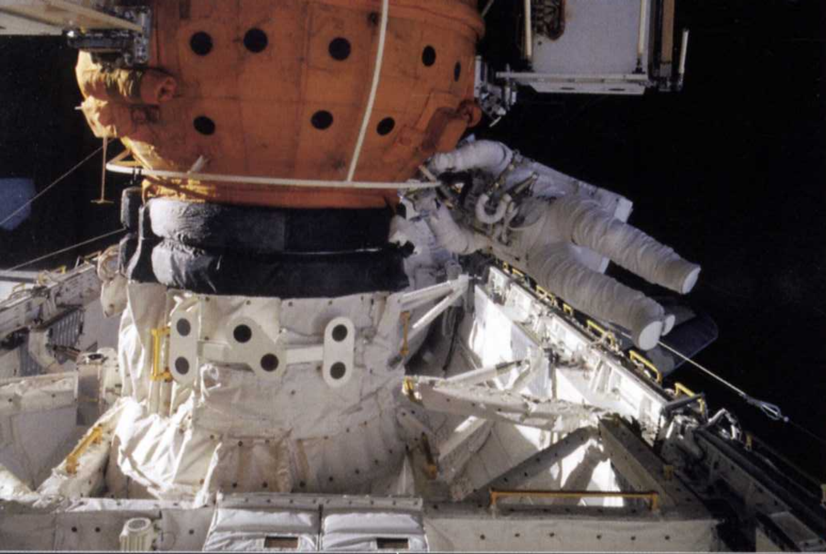
15 November 1988
Buran makes a successful automatic flight.

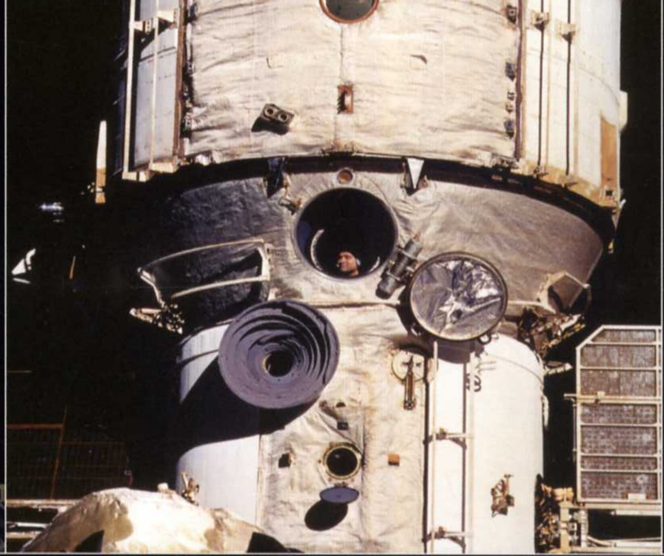
30 June 1993
President Yeltsin of Russia cancels the MKS project.

TECHNOLOGY

THE ENERGIA LAUNCHER

With a central core surrounded by strap-on boosters, Energia resembled many past Soviet rockets, but it was also a modular system – different configurations of boosters, and even extra stages stacked on the rocket, could turn it into a general-purpose heavy launch vehicle. Even without Buran, Energia could have had a useful role as a launcher, but it was ultimately cancelled with the rest of the MKS, leaving the Proton as Russia's heavy-lift rocket of choice.



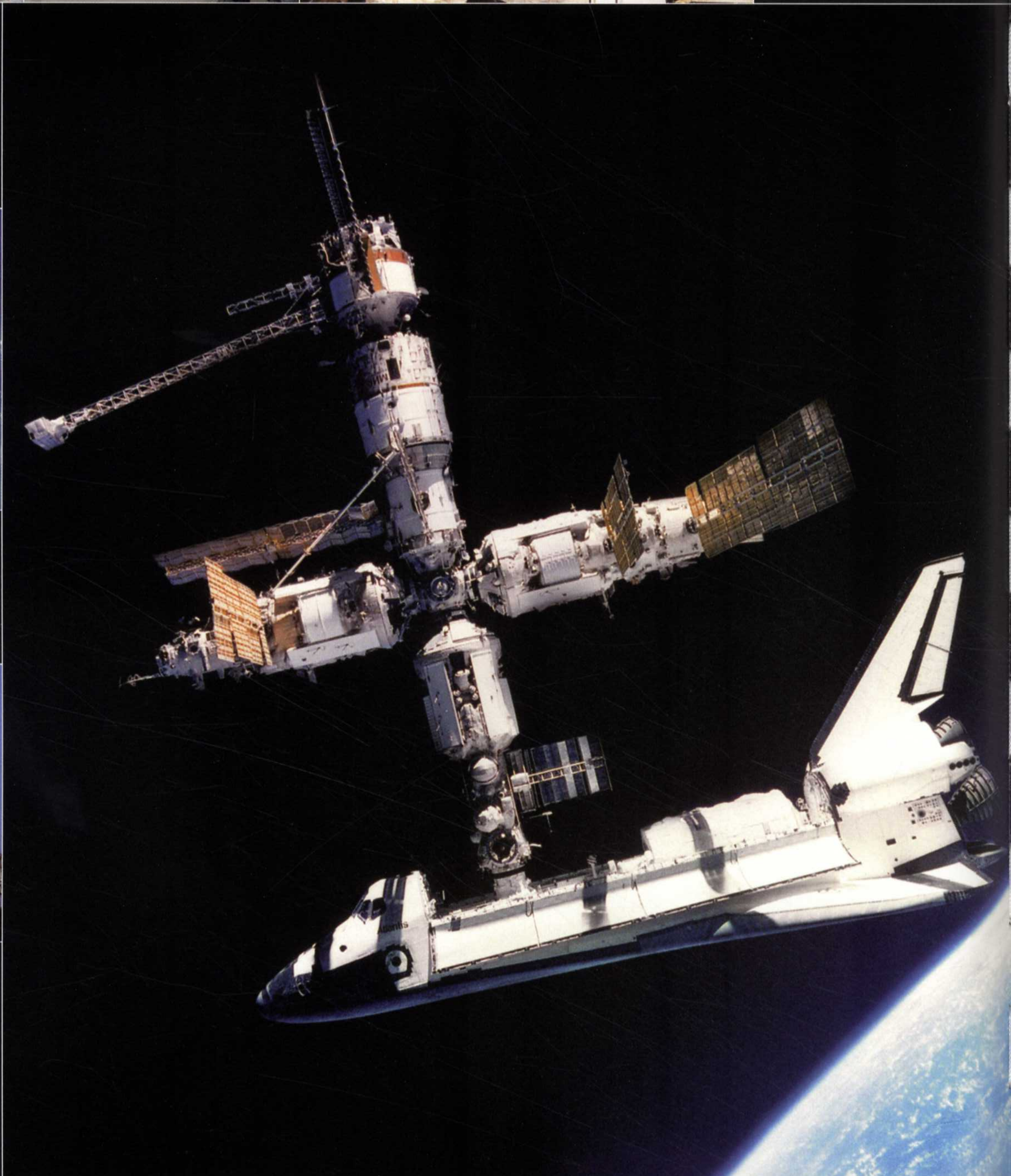


NEAR MIR
The crew of Discovery *photographed cosmonaut Valeri Polyakov watching their close approach in February 1995. Polyakov, an expert in space medicine, was nearing the end of a record-breaking 14-month endurance mission aboard Mir.*

ORBITAL UPGRADE
Astronaut Rich Clifford works on the Mir docking module during STS-76 in March 1996. Although tethered to the Shuttle, Clifford also tested a new emergency manoeuvring unit called SAFER.

APPROACHING MIR
Atlantis *photographed Mir hanging above the Earth shortly before the third docking of the spacecraft, in March 1996.*

STS-86 ROLLOUT
Atlantis *made seven flights to Mir from 1995–97. A refit in late 1997 led to* Endeavour *and* Discovery *making the last two flights.*



Working together

The collapse of the Soviet Union and the chaos that followed in its successor states finally brought the Russian and American space programmes together for a series of daring Shuttle–Mir missions.

JOINT MISSION
The STS-71 mission patch refelected Atlantis*'s historic link-up with Mir. As was as helping to create the then largest man-made object in space, the mission was also the USA's 100th manned spaceflight.*

ATLANTIS DOCKED
Cosmonauts Solovyov and Budarin photographed the united Shuttle and space station during STS-71 on 4 July 1995. The cosmonauts had boarded a Soyuz spacecraft for an inspection "flyaround" prior to the departure of Atlantis*. Together, station and Shuttle comprised by far the largest structure ever put into space.*

The Soviet Union's dramatic disintegration at the end of 1991 left its space programme in chaos. While much of its infrastructure was inside Russia itself, some vital assets were beyond Russian borders in suddenly independent states. Kazakhstan, for instance, was soon demanding payment for use of its launch facilities at Tyuratam.

Meanwhile Mir remained in orbit, its politically stranded cosmonauts Alexander Volkov and Sergei Krikalev dubbed "the last Soviet citizens". Cash shortages meant the station was still only half-finished, with two large modules still waiting on the ground. Eager to extend the hand of friendship and help stabilize the fragments of their former rival, American politicians saw the possibility of once more turning space exploration to political ends.

In June 1992, US President George Bush and Russia's new President Boris Yeltsin announced their intention to cooperate in space. NASA Administrator Dan Goldin and Yuri Koptev, director of the newly formed Russian Space Agency (RSA), soon agreed a tentative programme of astronaut exchanges. With the aid of a substantial cash injection from NASA, normal service on Mir was resumed, and in February 1994 Sergei Krikalev became the first cosmonaut to fly aboard the Shuttle. By this time, the new Clinton administration had broadened the scope of cooperation with the Russians, who were to become major partners in the International Space Station (ISS – see p.286). A series of joint Shuttle–Mir missions would help keep the Russian station operating and give NASA astronauts experience of long-duration spaceflight before construction work on the ISS started in the late 1990s.

BIOGRAPHY

HELEN SHARMAN

Briton Helen Sharman (b.1963) became her nation's first astronaut with an eight-day stay aboard Mir in May 1991. Food scientist Sharman was selected in 1989 – one of thousands who applied for the Project Juno mission, intended to be sponsored by British business. She spent 18 months in training at Star City, and when the fee for her trip could not be raised, the Soviet Union agreed to let her fly in exchange for her assistance in their own experiments.

Shuttle–Mir

In order to dock with Mir, one Shuttle would have to be fitted with a special adaptor, and *Atlantis* was chosen for the upgrade. Following a close orbital rendezvous by *Discovery* in early 1995, *Atlantis* and Mir docked in space on 29 June. In the meantime, one of Mir's remaining elements, the Spektr Earth-sciences module, had finally been launched, now fitted out with additional equipment needed for NASA's own programme of experiments.

An American astronaut, Norman Thagard, had also been aboard Mir for more than three months. For this first visit, *Atlantis* brought with it a Spacelab module fitted with equipment to assess the health of the station's outgoing crew. The incoming crew also included two Russian cosmonaut passengers who would take over on Mir – Anatoli Solovyov and Nikolai Budarin.

Later visits brought new equipment and supplies to Mir, as well as ferrying personnel to and from the station. A new docking adapter was fitted that allowed the Shuttle to dock in a more convenient configuration, and in April 1996 the Priroda module was finally added to Mir. This last element of the station contained remote-sensing and materials-science equipment.

TECHNOLOGY

EXERCISE IN SPACE

Long stays on Mir meant that American astronauts had to get used to the exercise regimes cosmonauts had been practising for years. While it was relatively easy to recover from a few days of weightlessness aboard the Shuttle, months in orbit had greater physiological effects, and astronauts such as Shannon Lucid used Russian equipment to keep fit in space. With no gravity to work against, most of the exercise devices forced the user to work against tension or interia. These included a cycling machine and a treadmill with elastic attachments to strap down the user.

3 February 1995
Discovery comes within 10m (33ft) of the Russian space station during the STS-63 "Near Mir" mission.

1 June 1995
The Spektr module docks successfully with Mir.

29 June 1995
Atlantis and Mir dock for the first time during the STS-71 mission.

14 November 1995
Atlantis STS-74 adds a docking module to Mir.

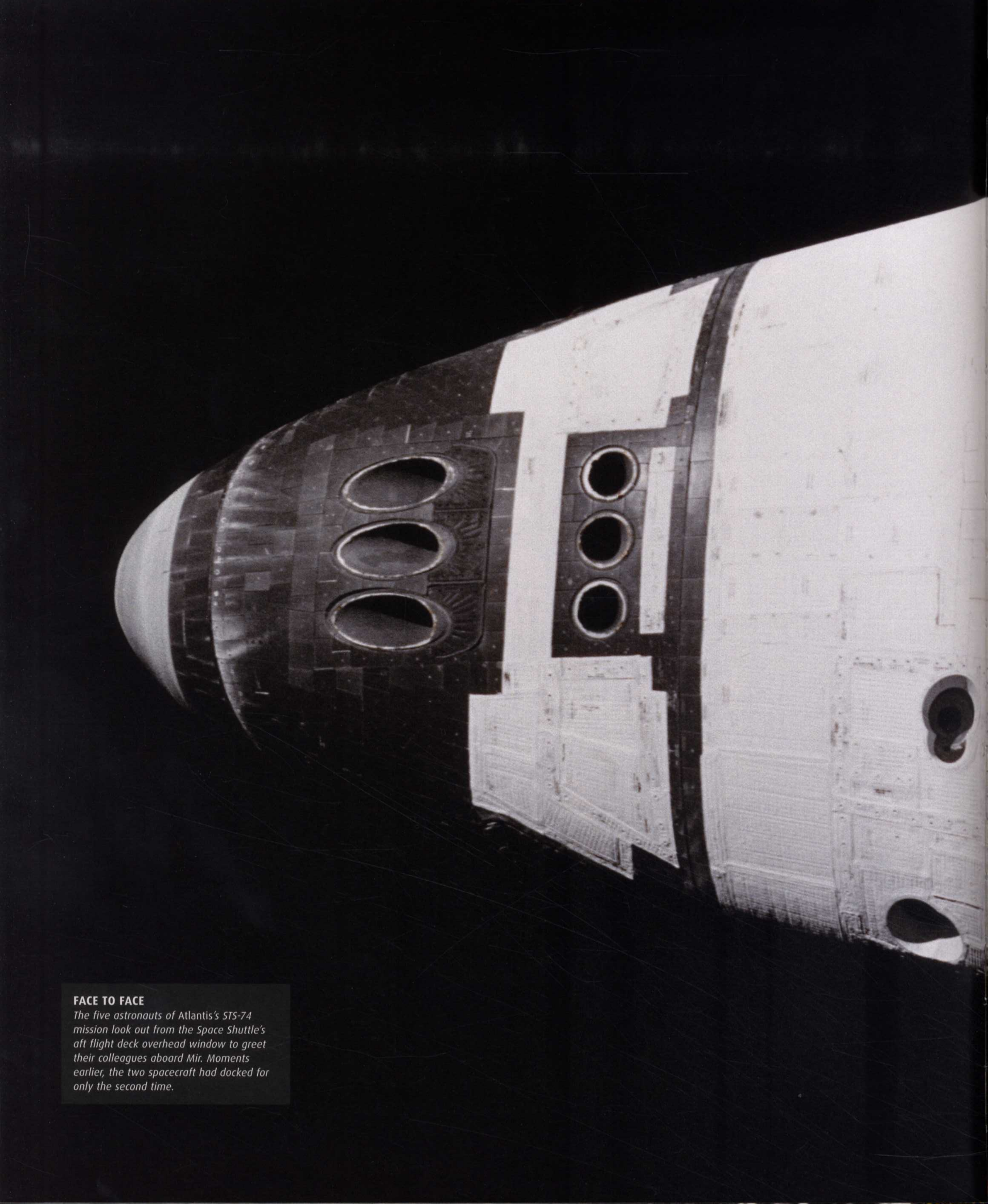
24 March 1996
STS-76 ferries equipment to and from Mir and leaves a new American crew member, female astronaut Shannon Lucid.

26 April 1996
Priroda, the last of Mir's main modules, is joined to the station.

15 January 1997
Atlantis STS-81 collects John Blaha and leaves Jerry Linenger as Mir's new long-term guest.

17 May 1997
Atlantis STS-84 docks with Mir. Jerry Linenger is replaced by British-born astronaut Michael Foale.

27 September 1997
Atlantis STS-86 arrives at Mir to collect Michael Foale and leave David A. Wolf onboard.



FACE TO FACE
The five astronauts of Atlantis*'s STS-74 mission look out from the Space Shuttle's aft flight deck overhead window to greet their colleagues aboard Mir. Moments earlier, the two spacecraft had docked for only the second time.*

The end of Mir

Throughout the later Shuttle–Mir missions, the Russian space station was showing its age. When ambitious schemes to keep Mir running as a private concern came to nothing, the station was doomed to a fiery end.

FINAL MISSION
Cosmonauts Sergei Zalyotin (centre) and Alexander Kaleri set out on what would prove to be the last visit to Mir, in April 2000.

24 January 1998
Endeavour STS-89 arrives to retrieve David A. Wolf and deliver Andy Thomas, Mir's last American resident.

4 June 1998
Discovery docks with Mir during its STS-91 mission.

8 June 1998
Discovery undocks from Mir, marking the end of the Shuttle–Mir programme.

22 February 1999
French spationaut Jean-Pierre Haigneré arrives at Mir aboard Soyuz-TM 29, to work alongside the last Russian crew.

28 August 1999
Mir's final working crew mothball the station and return to Earth at the end of almost ten years of continuous occupation.

6 April 2000
Cosmonauts Alexander Kaleri and Sergei Zalyotin return to Mir and revive it for a possible new life as a commercial venture.

23 March 2001
Mir re-enters the Earth's atmosphere and burns up over the Pacific Ocean.

American astronauts visiting Mir found the station ran along unfamiliar lines. While NASA controllers micromanaged each Shuttle astronaut's day in blocks of activity, Mir cosmonauts were allowed to organise much of their own time. Although partly an inevitable consequence of Mir's limited contact with the ground (the Russians had no equivalent of NASA's TDRS satellite system to maintain constant contact), the Americans soon found they enjoyed their independence during such long missions – a lesson that would be applied when it came to managing the ISS.

The coming together of space programmes also emphasized other differences between them – most significantly, how rapidly Mir was aging compared to the frequently serviced, constantly refurbished Shuttle. Every month seemed to bring a new snag, ranging from leaks to power failures and even bumps from Soyuz and Progress spacecraft flying close to the station. However, the worst crises were undoubtedly the fire of February 1997 (see over), and the collision of Progress-M 34 with the Spektr module four months later (see panel, opposite).

The final phase

Discovery's departure in June 1998 marked the end for a chapter in US–Russian space co-operation. The first segments of the ISS would soon be in orbit, and NASA was keen for the RSA to dedicate its limited resources to the new project rather than sustaining the crumbling Mir. The RSA duly announced that the station would be deliberately taken out of orbit the following year.

Nevertheless, the end of Shuttle visits saw a temporary return to business as usual on Mir, as Talget Musabayev and Nikolai Budarin resumed work. In the following months crew rotations continued, and Mir welcomed a variety of guests, including Yuri Baturin, a distinguished space physicist and former adviser to President Yeltsin, who opined that Mir should be funded for another two years. Delays to the ISS brought more calls to extend Mir's life, but without money there was little the RSA could do.

Meanwhile RSC Energia (the company that now actually owned Mir) sought private funding to continue operation. One important element of this was the ongoing guest cosmonaut programme, which culminated in a six-month tour for France's Jean-Pierre Haigneré from February 1999. In January, Yuri Semenov (see panel, above) announced a potential investor, but by the end of February, that hope had evaporated. Viktor Afanasayev and Sergei Avdeyev closed down much of the station before departing with Haigneré on 28 August 1999. The RSA now planned to bring Mir down early in 2000, while they could still guide it to a safe crash site – but there was one more twist to come.

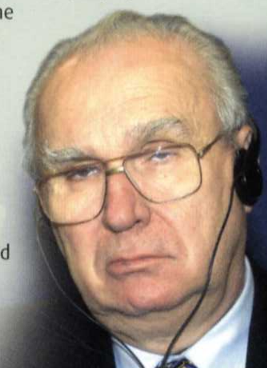
In January 2000, Energia announced investment from MirCorp, a company that would run the station for research and tourism. To NASA's annoyance, the RSA supported the venture, launching a ferry to boost Mir's orbit in February, and a ten-week Soyuz mission in early April to carry out repair and servicing work.

Throughout 2000, MirCorp announced various schemes – plans to launch an actor into space, a gameshow contest for a flight aboard Mir, and even the first space tourist, one Dennis Tito (see p.308). But launch dates continued to slip, and Energia eventually accepted the inevitable, terminating the deal in December. Mir's impressive career finally ended with a spectacular demise over the Pacific in March 2001.

BIOGRAPHY

YURI SEMENOV

After engineering studies and work for another missile design bureau, Yuri Pavlovich Semenov (b.1935) transferred to Korolev's OKB-1 in 1964. He soon became Deputy Leading Designer on the Soyuz project and then Leading Designer of the abandoned L1 Moonship. Through the 1970s and 1980s, he was Chief Designer (under Designer General Valentin Glushko) for the Soyuz, Salyut, Mir, and Buran projects. He took over at the head of NPO Energia in 1989 and led it in its various subsequent incarnations until his retirement in 2005.



LAST MOMENTS OVER FIJI
On 23 March 2001, the Progress-M1 ferry attached to Mir fired its engines to lower the station's orbit and plunge it into the Earth's atmosphere.

1998

MIR SHOWS ITS AGE
Looking somewhat battered by a series of accidents and the general wear and tear of 12 years in space, Mir was photographed by Discovery *in June 1998 during the final Shuttle–Mir mission.*

HISTORY IN FOCUS

COLLISION IN SPACE

On 25 June 1997, a Progress-M ferry being used for a remote piloting test crashed into a solar panel on Mir's Spektr module, creating a substantial leak. To save the station, Mir's occupants had to seal Spektr off, cutting internal cables that carried power from the module's solar panels. This left the station short of power, and it had to be steered for some time using the engines on the attached Soyuz spacecraft. Locating the leak near the panel's motor took some time, and it took several months and a number of spacewalks to get Mir fully operational once again.

EXPERIENCE

EMERGENCY IN ORBIT

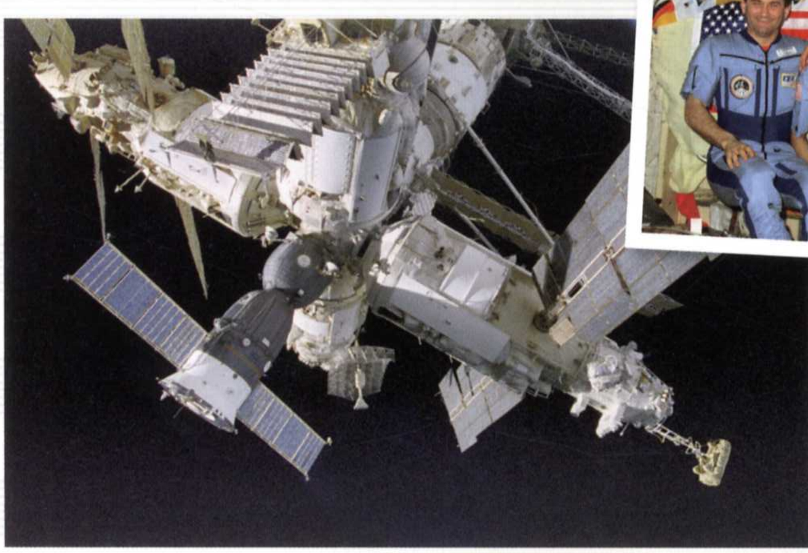
Fire on Mir

JERRY LINENGER
NASA astronaut Linenger was the fourth American aboard Mir. As the station's physician, he had special duties in the emergency – watching in case anyone fell ill and keeping a particular eye on Korzun as he fought the fire.

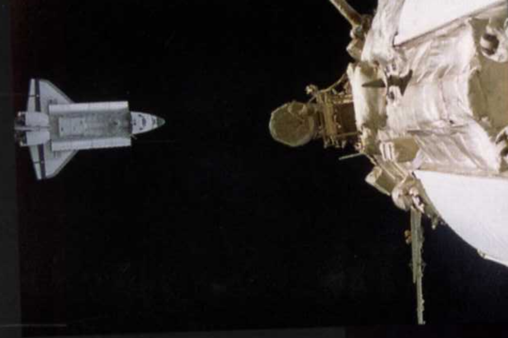
By the mid-1990s, Mir was approaching a decade of continuous operation and had started showing its age. In addition, a series of accidents and mishaps threw the station's future into doubt. Of these, the most dangerous was the fire of February 1997.

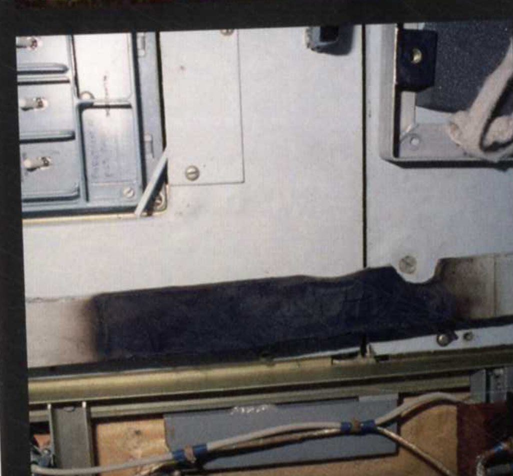
The fire broke out during one of Mir's crowded handover periods – Soyuz TM-25 had arrived 12 days earlier, bringing Vasily Tsibliev, Aleksandr Lazutkin, and German visitor Reinhold Ewald. The American Jerry Linenger had been aboard for several weeks, while Valeri Korzun and Alexander Kaleri were near the end of their mission. The six residents were supplementing the station's air supply with solid-fuel oxygen generators (SFOGs) that produced oxygen through a slow chemical reaction. After dinner on 24 February, Lazutkin went to activate another SFOG cylinder in the Kvant module when it erupted in a shower of sparks – a "baby volcano" as Lazutkin described it. Ewald spotted the fire and alerted the rest of the crew, with Korzun clambering through the hatch to pull Lazutkin from the flames. A wet towel had little effect and Korzun called for fire extinguishers – but the first one he tried failed to work. As the smoke grew worse, and the crew put on oxygen masks, the fire alarm alerted Linenger, who had retired early to bed:

" **The smoke was immediate.** It was dense ... I could see the five fingers on my hand, I could see a shadowy figure of the person in front of me who I was trying to monitor to make sure he was doing okay ... Where he was standing he **could not see his hands in front of his face**. In the distant modules ... the smoke was still dense, so it was very surprising how fast and rapid the smoke spread throughout the complex ... I did not inhale anything, and I don't think anyone else did because the thickness of the smoke told you that **you could not breathe**. So, everyone immediately went to the oxygen ventilators. They worked very [well], and they protected us from inhalation injury."



AFTER THE FIRE
Jerry Linenger would continue his mission alongside Tsibliev and Lazutkin (above, left and right of Linenger) until May, when Atlantis arrived to collect him and deliver Michael Foale.





SITTING IT OUT
With the fire out, the crew had to wear their oxygen masks for several hours while Mir's air filters did their work and the smoke cleared. With so many oxygen masks used, they had to preserve those remaining if all six crew were to remain on the station.

"When I saw the ship was full of smoke, my natural earthly reaction was to want to open a window. And then, **I was truly afraid** for the first time."

Aleksandr Lazutkin, interviewed by Nova TV, 1998

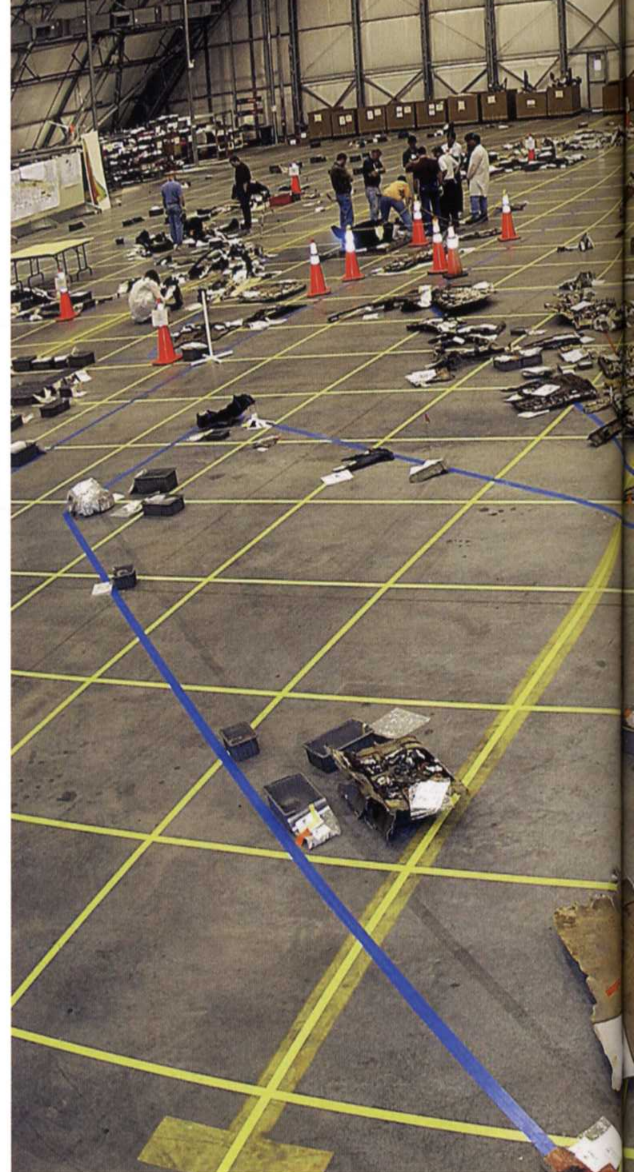
Korzun told Lazutkin to prepare one of the two Soyuz spacecraft for evacuation. But there was a problem – the other Soyuz lay on the other side of the fire. As Linenger arrived, the Russian commander ordered the crew to work in pairs, in case one was overcome by smoke. Ewald fetched more oxygen masks (some did not seem to be working), while Tsibliev and Linenger collected fire extinguishers from around the station, before returning to the base block. Eventually, the fire was out – but smoke lingered in the station for some time. Oxygen masks were also running short, and it was some hours before the risk of an evacuation was over.

INFERNO IN SPACE
Linenger had arrived on the Shuttle Atlantis in mid-January and begun a programme of biomedical science. The fire broke out in the crowded Kvant-1 module and, though brief, coated surfaces throughout the station in a thick layer of grime. Thankfully, aside from the destroyed SFOG canister, there was no serious damage.

"I grabbed the respirator off the wall, activated it, took a breath, and I **didn't get any oxygen**. At that point, there was a lot of smoke. I took the mask off. Again, Earth instinct made me look low to **try to find a clear spot** where I could get a quick breath because I was getting very short of breath at that time. But it was solid smoke. **Smoke does not rise in space** like it does on the ground. It's just everywhere. I went to the other respirator on the other wall. Opened it up. At that point, Vasily was there. He saw **I was getting into trouble.** He helped me get the thing out. I activated it again. Put it on. Breathed in, and luckily got oxygen at that point."

Jerry Linenger, interviewed by Nova TV, 1998

EXPERIMENTAL PROGRAMME
During Linenger's 132-day stay on Mir, he concentrated on life sciences and biotechnology, using his scientific background. He is shown here in Mir's Priroda module.



The loss of *Columbia*

The tragic loss of a second Space Shuttle in 2003 led to another hiatus in the launch programme, delaying the effort to build the International Space Station and ultimately changing the entire course of the US space effort.

While the Space Shuttle *Challenger* had been lost at the start of her flight, *Columbia* was minutes from home when disaster struck on 1 February 2003. The first signs that something was seriously wrong came with an apparently faulty indication that one of the tyres on the Shuttle's left wing had been deflated. Within seconds, however, temperature sensors both on and within the wing began to rise. The last communication from the Shuttle gave no indication that the crew knew they had a major problem, but at 8:59am EST, telemetry data was abruptly lost. Then reports started to come in of fireballs seen in the sky over Texas, and smoking debris falling to the ground. It was soon clear that *Columbia* had broken up during re-entry.

ILL-STARRED MISSION
Columbia *soars skyward on 16 January 2003, its underside already damaged by the fatal impact that would doom its return to Earth 16 days later.*

Fatal impact

Tragically, the cause of this disaster had been spotted during the launch, but a series of mistakes led managers and engineers to underestimate the danger to the Shuttle. Stress and vibration during *Columbia*'s launch 16 days earlier had shaken loose a large chunk of lightweight insulating foam from the bipod struts that supported the Shuttle's nose above the external tank. As the foam flew off, ground-based video cameras saw it strike *Columbia*'s wing.

NASA immediately began to assess the risk, but managers felt that comparisons with similar impacts in the past (often noticed only when the orbiter returned to Earth with scars) suggested there was little to worry about. But several key factors had been missed – the lost chunk of foam was much larger than on any previous mission, and struck the Shuttle at a different angle and at much higher speed. And although no one could have known it, the debris had hit a very vulnerable spot – the leading edge of the wing, which received most of the heat during re-entry. As *Columbia* re-entered the atmosphere at 24 times the speed of sound, the usual sheath of hot gases developed around it, but found their way inside the Shuttle through the hole in the wing. At an altitude of 70km (44 miles), the orbiter's wing broke up, taking the rest of *Columbia* with it.

ALL LOST
(Left) The crew shortly before setting off on the STS-107 mission. Tragically they all perished when Columbia *broke up in the skies over Texas (right).*

"Their mission was almost complete, and **we lost them so close to home**."

President George W. Bush, 4 February 2003

POST MORTEM
The break-up of Columbia *scattered debris across a large swathe of the southern United States. Accident investigators collected as much as possible and, applying the same technique used with other air crashes, laid the pieces onto an outline of the orbiter marked out inside one of the hangars at Kennedy Space Center.*

The aftermath

Following guidelines set up after the *Challenger* disaster, an expert committee, the Columbia Accident Investigation Board, was immediately estabilshed to discover what had gone wrong. It took some time to conclude that a piece of lightweight foam had indeed doomed the spacecraft, but debris collected from along the re-entry path soon revealed the story of *Columbia*'s break-up in detail. When the Shuttle's black box flight recorder was found, it confirmed that the trouble had started on the left wing.

Once again the Shuttle fleet was grounded for modifications, and once again the verdict on NASA management was damning – but this time the effects went further. Construction of the International Space Station (ISS) ground to a halt (see p.296), and NASA had to rely on Russian launches to keep the station crewed and supplied.

In the longer term, the loss of a second orbiter was too much for the Shuttle programme to bear – it was now clear that a large spacecraft strapped alongside its fuel tank and boosters was vulnerable to accidents that would not affect other vehicles. In economic terms, the problems were even clearer – the development of rival rockets and commercialisation of the launch market, coupled with the Shuttle's relatively slow launch rate, had already made it clear that the Shuttle would never undercut the competition. After *Challenger,* most routine satellite launches, even for NASA missions, had returned to unmanned rockets, with the Shuttle reserved for more ambitious tasks. *Columbia* decided the issue, and in January 2004, President Bush announced that the Shuttle would be retired as soon as its construction work on the ISS was complete. It was the end of an era for manned spaceflight.

TECHNOLOGY

LESSONS LEARNED

When the Shuttle returned to space again in July 2005, NASA had a far more cautious attitude. Tiles in vital areas would now be inspected in space, either during a spacewalk, or using a new camera attached to the robot arm. Despite all the safety improvements, though, checks during *Discovery*'s initial return to flight mission revealed that there were still minor problems with the tiles and gave the astronauts onboard a chance to test new techniques for carrying out in-orbit repairs.

16 January 2003
With its planned launch delayed 18 times over a two-year period, *Columbia* finally lifts off on the STS-107 mission to conduct microgravity and Earth science research.

17 January 2003
Routine analysis of launch images reveals a large chunk of debris from the ET support strut potentially striking the Shuttle's left wing.

19 January 2003
Engineers requests for an emergency spacewalk to inspect the Shuttle's wing are ignored by NASA.

22 January 2003
Requests from NASA engineers for Department of Defense technology to image the Shuttle in orbit are withdrawn by NASA management.

1 February 2003
Columbia disintegrates on re-entry to Earth's atmosphere. The crew of Kalpana Chawla, Ilan Ramon, William McCool, Michael Anderson, Laurel Clark, David Brown, and Rick Husband are all killed. All Shuttle flights are suspended.

26 August 2003
The Columbia Accident Investigation Board issues its report.

ENGINES OVER EARTH
This spectacular close-up of the Space Shuttle Discovery's *tail section was taken from the International Space Station. The rear of the Shuttle is covered in rocket nozzles, including the main engines, the smaller OMS engines used in orbit, and the RCS attitude adjustment thrusters.*


Discover

20 March 1964
ESRO and ELDO come into existence.

4 June 1964
The first test launch of the Europa project, firing a Blue Streak missile at Woomera, is successful.

14 November 1966
A test launch of the modified Europa first stage with dummy upper stages succeeds.

4 August 1967
In the first test of Europa with an active second stage, the upper stage fails to ignite.

3 October 1968
The first European satellite, ESRO 1A, reaches orbit on a NASA Scout B rocket.

12 June 1970
After a string of accidents, the last Europa launch from Woomera fails to deploy a satellite when the payload shroud jams.

5 November 1971
A final Europa launch from Kourou fails due to a guidance problem in the third stage. The project is suspended for review, then cancelled.

European space efforts

The smaller nations of Europe could not hope to compete individually with the massive space efforts of the superpowers, but by banding together they ultimately became a significant space power.

Britain and France began to develop their own ballistic missile programmes well before the launch of Sputnik 1, and scientists and engineers on both sides saw the potential for turning these weapons into satellite launchers (see p.56), but it was soon clear that neither nation had the resources to pursue a major space programme on its own. The drive towards closer political cooperation in western Europe, however, meant that a Europe-wide space effort would be a natural progression.

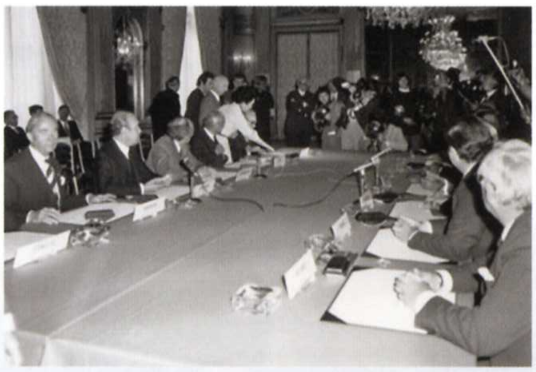
The first sign of this new policy was the formation of the European Space Research Organisation (ESRO) in 1964. France, Britain, and Germany were its leading players and contributed most of the budget, but there were seven other initial members – Italy, Belgium, the Netherlands, Sweden, Denmark, Spain, and Switzerland.

ESRO's main purpose was to coordinate European space policy and direct research efforts for the peaceful use of space. Over the next ten years, the organisation developed seven scientific satellites – four that studied the Earth's upper atmosphere and aurorae (the northern and southern lights), two that studied the Earth's magnetic field and the solar wind, and an orbiting ultraviolet observatory.

A European launcher

Each of ESRO's satellites ultimately had to rely on an American rocket to put it into space, but it seemed obvious that Europe should have its own launch vehicle. After Britain's attempts to develop the three-stage Black Prince launcher with partners from the British Commonwealth came to nothing, the project was taken over by the European partnership. A new agency, the European Launcher Development Organisation (ELDO), was set up to coordinate its

DUMMY LAUNCH
In this test launch of the Europa launch vehicle at Woomera in 1966, only the lower stage (modified from Blue Streak) is active – the rest of the rocket and a satellite onboard are dummies.



EUROPEAN UNION
Representatives of the ten ESRO member states sign the new European Space Agency into being. ESA formally took over ESRO and ELDO operations on 31 May 1975.

development – it included six members of ESRO and also Australia. The new Europa launch vehicle, as it was known, was to use Britain's Blue Streak missile as its base, with upper stages provided by France and Germany. Italy took responsibility for the payload fairing, the Netherlands for telemetry systems, and Belgium for the ground tracking, while the launch site would be at Woomera, Australia.

With so many contributions from isolated teams in various countries and no overall firm leadership, the Europa project proved the impossibility of launch-vehicle design by committee. While the Blue Streak-based stage performed reliably throughout a series of launches from 1966 onwards, either the French Coralie second stage or the German Astris upper stage failed in each case. The British decision to discontinue all work on Blue Streak in 1968 finally sealed the project's fate.

ESA'S FIRST SATELLITE
The Cos-B gamma-ray observatory, launched for ESA by a US rocket on 9 August 1975, was largely developed under ESRO. Like many of their satellites, it was a great success.

A new beginning

Inquests into the death of Europa laid much of the blame at the feet of ELDO itself. It was clear that Europe would not step back from space completely – even in the darkest hours of the Europa project, France was using its Diamant launcher for successful launches from both Algeria and its new facility in Kourou, French Guiana. But Britain was rapidly losing confidence in the future of space exploration, and after the cancellation of the Black Arrow project in 1971, it largely restricted itself to scientific contributions to various satellites. ELDO had been critically undermined by the Europa failure, and while France was eager to develop a new pan-European launcher as a successor to Diamant, it wanted the largest share of the work and the final say in many elements of the new programme. The other nations were only too happy for France to shoulder the burden, and so in May 1975 the European powers united all their joint space efforts in a single new organisation – the European Space Agency.

The fledgling agency would inherit all of ESRO's projects and use many of the facilities of the French CNES space agency, including its launch centre at Kourou. One of the first satellites launched under the new ESA regime was the gamma-ray astronomy observatory Cos-B, though this mission, like previous European satellites, was carried into orbit by an American Delta rocket. The situation could not last, however – the development of microelectronics was already paving the way for the commercial satellite boom of the late 1970s, and ESA wanted its share of what would surely become a lucrative market.

ROCKET ASSEMBLY
ESA's launcher systems are all tested at the 58m- (190ft-) high Launcher Integration Building at Kourou. From here, rockets are transferred along a rail track to the Final Assembly Building, and then on to the launch pad.

GUIANA SPACE CENTRE
(Left) France selected Kourou for its new launch centre because of its near-ideal location. At latitude 5°N, rockets get a large speed boost from the Earth's rotation as they are launched towards the Atlantic. (Below) An ESA Ariane 5 rocket is being readied at Kourou's Launch Complex 3.

The European Space Agency

Since its formation in 1975, ESA has become a major player in the commercial launch industry. It has also developed many groundbreaking satellites and probes and sent astronauts into space in collaboration with other space powers.

31 May 1975
ESA is established by the ten ESRO member states.

9 August 1975
A US Scout rocket launches ESA's first satellite, Cos-B.

24 December 1979
The first test flight of Europe's Ariane launch vehicle is a success.

24 June 1982
Jean-Loup Chrétien becomes the first western European in space, aboard Soyuz T-6.

4 August 1984
Ariane 3 enters service, almost two years ahead of Ariane 2.

14 March 1986
ESA's first spaceprobe, Giotto, makes a successful flyby of Halley's Comet.

15 June 1988
Ariane 4 makes its first successful flight.

21 October 1998
After a pair of failures, Ariane 5 enters service with a successful launch.

30 June 2005
Luxembourg becomes ESA's 17th member state.

A major pillar of ESA's success has been the Ariane launcher, developed largely by the French CNES space agency. After the problems with the Europa project, France contributed 60 per cent of the development costs in return for control of the project. Germany put in another 20 per cent, with the other ESA nations making up the remainder. Ariane I, with its first and second stages powered by French Viking engines, was low-tech but reliable. A successful maiden flight in 1979 paved the way for 11 more launches, with only two failures early in the programme.

Arianes 2 and 3, which entered service in the mid-1980s, were essentially similar rockets, though Ariane 3 had strap-on boosters. They and their successor, Ariane 4, had very good success rates, allowing Arianespace, a company formed to run the commercial launch operation, to take a substantial segment of the satellite launch market. Today, ESA operates the new heavy-lift Ariane 5 (see over) and is developing a solid-rocket launcher called Vega for smaller payloads. Meanwhile, the organization has grown from its initial ten member states to 17.

BIOGRAPHY

JEAN-LOUP CHRÉTIEN

Europe's first astronaut (or spationaut) was French air force pilot Jean-Loup Chrétien (b.1938). He was first selected as a candidate for cosmonaut training when the Soviet Union offered France a place in its Intercosmos programme (see p.240) and flew to Salyut 7 aboard Soyuz T-6 in June 1982. Appointed head of the CNES Astronaut Office, he was backup for the first spationaut to join the Space Shuttle in 1985 and flew on another Soviet mission, this time to Mir in 1988. Moving to America, he retrained with NASA and returned to Mir aboard *Atlantis* in 1997. He retired in 2001.

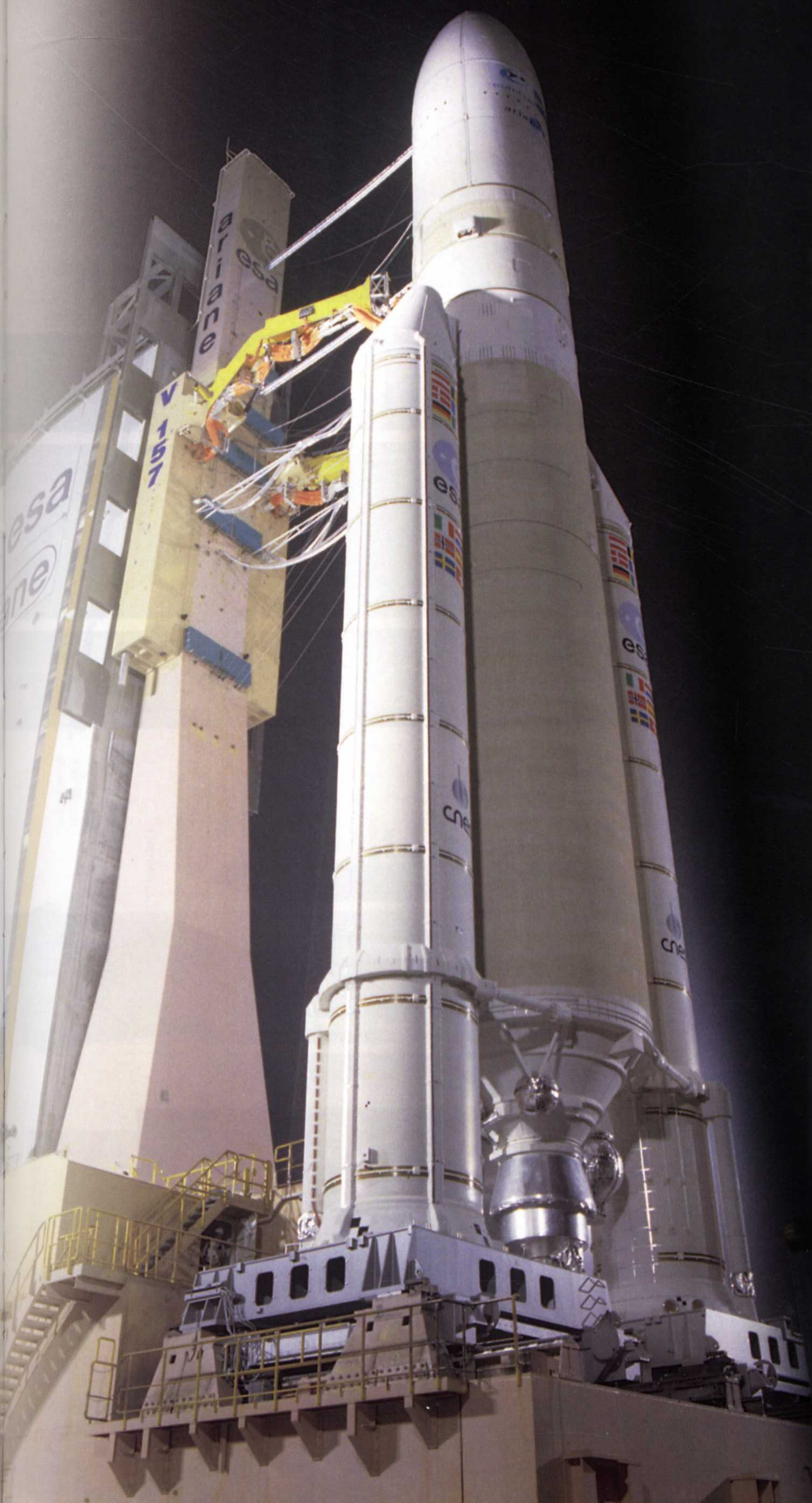
Probes and satellites

ESA inherited a number of satellite projects from ESRO and has since expanded into nearly all the main satellite applications. Astronomical observatories have included Cos-B, Hipparcos (a survey telescope that measured the properties of half a million stars) and the Infrared Space Observatory (ISO). The Agency has developed a particularly successful series of remote-sensing satellites: its Earth resources satellite ERS-1 was among the first to carry synthetic aperture radar (see p.267) and was followed up by ERS-2 and Envisat, which carries an array of instruments to monitor climate change.

Further afield, Europe made a spectacular space-exploration debut when its Giotto probe flew past the nucleus of Halley's Comet in 1986 (see p.272). Since then, ESA has contributed the Huygens Lander to the Cassini Saturn mission, launched its own planetary orbiters – Mars Express and Venus Express – and built a number of smaller probes, including the highly successful SMART-1, an experimental spacecraft powered by an ion drive (see p.257). Future plans are even more ambitious – the Rosetta mission currently on its way to Comet Churyumov–Gerasimenko will go into orbit around and deploy a lander to sample the comet's surface, while the BepiColombo mission (developed with Japan's JAXA agency and still in its planning stages) will put a pair of complementary spacecraft in orbit around Mercury.

ASTRONAUT TRAINING
ESA astronauts Pedro Duque (Spanish, seated left) and Paolo Nespoli (Italian, seated right) train for flights aboard the ISS. Training at the European Astronaut Centre in Cologne is supplemented with training at Houston and the Gagarin Cosmonaut Training Centre.

ARIANE 1 LAUNCHES
The successful launch of Ariane 1 in December 1979 pointed the way to Europe's future in space. Although there were still some teething troubles to come, ESA's rockets have established an almost unrivalled record of reliability.



ARIANE 5 ECA
An upgraded version of Ariane 5 waits on the pad at Kourou prior to a (failed) launch in December 2002. The ECA variant has the capacity to take payloads of up to 10,500kg (23,100lb) into geostationary transfer orbit.

European astronauts

ESA maintains its own astronaut corps, based at the European Astronaut Centre in Cologne, Germany. Attempts to develop a small manned spacecraft called Hermés stalled in the early 1990s (see panel, below), but ESA astronauts have flown as guest cosmonauts on Soyuz launches (see panel, opposite, and p.240) and as payload specialists on a number of Space Shuttle missions. The agency has supplied several components for the ISS (see p.286), and its laboratory module, the Columbus Orbital Facility, is due to launch in 2007.

European astronauts will help crew the station's expeditions, and ESA is developing the station's Automated Transfer Vehicle. Launched by Ariane 5, this unmanned spacecraft will carry supplies to the station, then remain docked for up to six months to provide additional working and living space.

Looking to the future, in 2003 ESA signed a deal with the Russian Space Agency (RSA) to launch Soyuz rockets from its Kourou spaceport. Kourou's equatorial location will boost the payload capacity of the Soyuz for Russian launches, and ESA will get access to another reliable launch vehicle. In another collaboration, ESA and the RSA are developing plans for a Soyuz-derived spacecraft, and Europe may help to make the Kliper spaceplane (see p.299) a reality.

TECHNOLOGY

HERMÉS

In the early 1980s, the French space agency CNES developed plans for a small spaceplane that could be launched on top of the forthcoming Ariane 5 rocket. Hermés was a mini Shuttle that, in some plans, might have been capable of carrying a crew of four and a medium-sized payload into orbit, gliding back to Earth after completing its mission. CNES persuaded ESA to adopt the project in 1987, with a planned first flight in 1998. But spiralling costs and safety modifications after the *Challenger* disaster eventually led to the project's cancellation in 1992.

EVOLUTIONARY LAUNCHER

The Ariane 4 (right) was the final stage in the development of the original Ariane launcher. Based on Viking engines made by the French company Societé Européenne de Propulsion, Ariane was upgraded throughout the 1980s, with the addition of longer stages, liquid- and solid-fuelled boosters, and more powerful rocket engines.

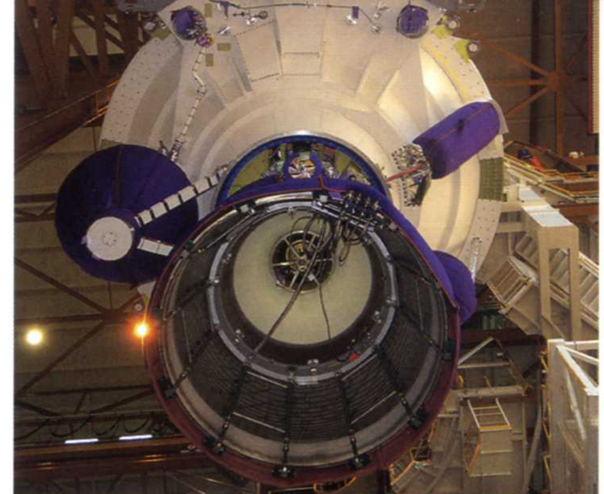
HEIGHT	58.4m (191ft 7in)
CORE DIAMETER	3.8m (12ft 5in)
TOTAL MASS	240,000kg (520,000lb)
ENGINES	4 +1 x Viking 2B (N204/UDMH) 1 x Viking 4B 1 x Viking 2B (upper stages)
THRUST AT THRUST	276,586kgf (608,490lbf)
MANUFACTURER	Aerospatiale

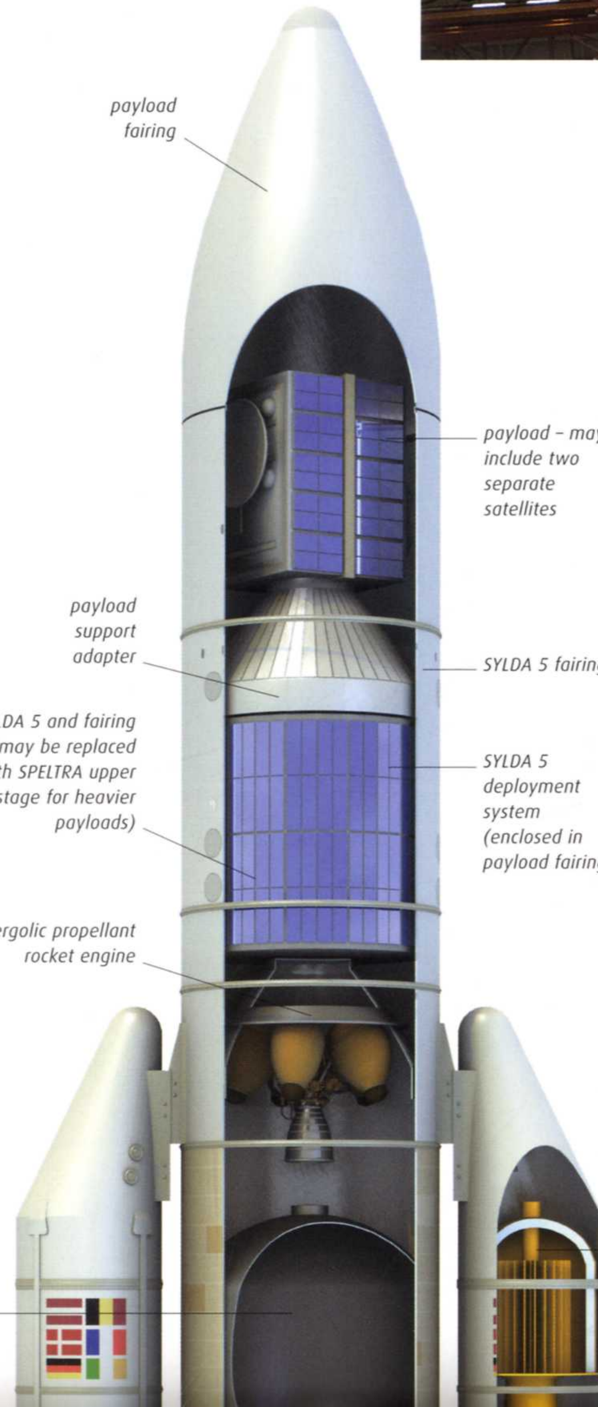
ARIANE 4 SECOND STAGE

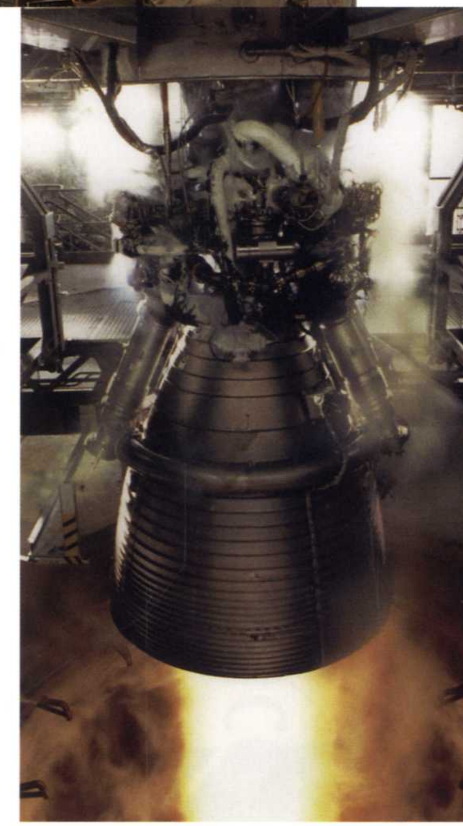
The 11.5m (37ft 8in) second stage remained externally the same throughout Arianes 1 to 4. The single rocket engine, however, was upgraded to a Viking 4B.

LAUNCH PREPARATIONS

The first stage of an Ariane 5 rocket is hauled upright within ESA's Launcher Integration Building at Kourou, French Guiana. Two solid rocket boosters will then be attached to the sides, and the upper stages and payload mounted on top.







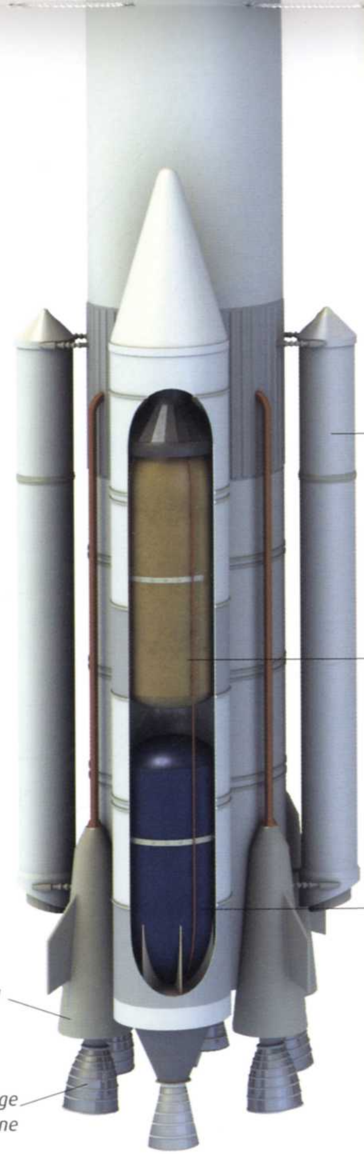
VULCAIN ENGINE

The new version of Ariane needs a different engine design to burn its cryogenic fuels, partly because they need an ignition trigger in order to burn. The new engine is called Vulcain.

Ariane launchers

ESA's Ariane launchers showcase two different approaches to launch-vehicle design. Ariane 4 was the final stage in the evolution of the original Ariane rocket, with a slender design harking back to the French Diamant of the 1960s. Its Viking rockets were also developed from the Vexin that powered Diamant, and it used traditional hypergolic propellants. Ariane 5, in contrast, is a totally new rocket built by the European Aeronautic Defence and Space Company (EADS) – the first European rocket to use cryogenic propellants.

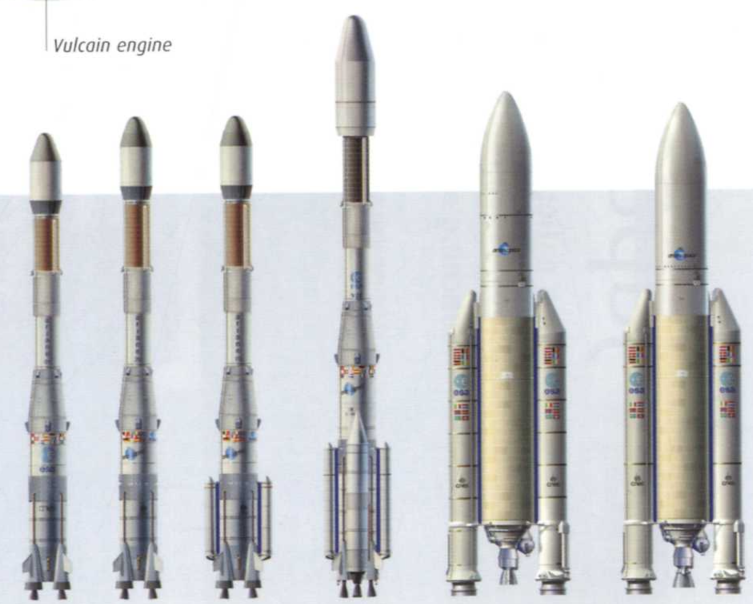
ARIANE 4 FIRST STAGE
The lower stage of Ariane 4 used four Viking 2B engines. These highly reliable engines, first introduced on the Ariane 2 and 3 variants, allowed the vehicle to make 113 successful launches throughout its career. The propellants, dinitrogen tetroxide (N2O4) and unsymmetrical dimethylhydrazine (UDMH), are hypergolic – they combust on contact and do not require low-temperature storage.



CRYOGENIC LAUNCHER
The Ariane 5 (left) is a completely new vehicle, developed in the 1990s. Unlike previous Ariane rockets, it uses liquid oxygen (LOX) and liquid hydrogen (LH2) as fuel for its central stage. These more powerful propellants need to be stored at low temperature and are termed cryogenic.

HEIGHT	54.05m (177ft 4in)
CORE DIAMETER	5.4m (17ft 8in)
TOTAL MASS	746,000kg (1,644,000lb)
ENGINES	1 x Vulcain (LOX/LH22) 2 x P230 SRBs
LAUNCH THRUST	1,162,531kgf (2,562,800 lbf)
MANUFACTURER	EADS

THE ARIANE SERIES
ESA's early rockets, from Ariane 1 (first launched in 1979) through to Ariane 4, were all evolutionary, developed from the basic design of Ariane 1. Ariane 5, conversely, was a completely new design, first launched in 1996 but not completely successful until its third flight, in 1998. It, too, is now proving reliable and has started to spawn its own family of "Ariane 5 Evolution" variants, typically using different upper stages on each launch.



11 February 1970
Japan's first satellite, Ohsumi, is launched into orbit by an ISAS rocket.

9 September 1975
A NASDA N-1 rocket launches the test satellite Kiku.

7 April 1978
NASDA launches an experimental direct broadcast television satellite called Yuri.

March 1986
The ISAS probes Suisei and Sakigake fly past Halley's Comet.

2 December 1990
Reporter Toyohiro Akiyama becomes Japan's first cosmonaut.

12 September 1992
Mamoru Mohri becomes the first Japanese astronaut to fly on the Space Shuttle.

1 October 2003
NASDA, ISAS, and the NAL are merged to form a new agency, JAXA.

19 November 2005
Japan's Hayabusa probe lands and tries to collect samples from the asteroid Itokawa.

Japan in space

For a nation that did not fire even an experimental rocket until the mid-1950s, Japan rapidly established itself as a force to be reckoned with, launching a multitude of satellites and spaceprobes from 1970 onwards.

OHSUMI
The 24kg (53lb) Ohsumi was purely a test satellite, sending out a signal that revealed its location and the readings of simple instruments onboard.

The beginnings of the Japanese space programme can be traced back to the enthusiasm of one man – aeronautical engineer and Tokyo University professor Hideo Itokawa, nicknamed Dr. Rocket. After conducting a number of successful launches of small rockets in the 1950s, Itokawa persuaded the Japanese government to fund his Institute of Space and Astronautical Science (ISAS).

In 1969 a second organization, the National Space Development Agency of Japan (NASDA) was established, charged by the government with turning Japan into a major space power. Although the presence of rival agencies led to occasional clashes, and split the available expertise, each body had its own specialist areas: ISAS concentrated on space research projects such as astronomy satellites and planetary probes, while NASDA focused on the development of commercial launch vehicles, other satellite applications, and manned spaceflight.

Both agencies had an impressive record of success throughout the 1970s and 1980s, but a series of expensive failures in the 1990s ultimately forced the Japanese government to merge them (along with NAL, Japan's National Aerospace Laboratory) into a new organisation, the Japan Aerospace Exploration Agency (JAXA) in 2003.

Launch vehicles and satellites

Under Itokawa's direction, ISAS developed a series of small solid-fuelled launchers known as the Lambda (L) and Mu (M) series from the 1960s onwards, and it was an L-4S that carried Ohsumi, Japan's first satellite, into orbit in February 1970. In keeping with the agency's main fields of interest, ISAS satellites focused on studying the environment around the Earth and on orbital astronomy. Successes include the Yohkoh solar observatory (a joint project with the United States and the United Kingdom) and the HALCA (Highly Advanced Laboratory for Communications and Astronomy) radio astronomy mission (see p.257)

NASDA's launchers, in contrast, were larger and liquid fuelled – their first N-series rockets were effectively US Deltas (see p.245) built under license in Japan. However, continued improvements have seen the Japanese rockets evolve along their own route, to a point where JAXA's current H-IIA has an entirely Japanese design (see panel, opposite).

An N-1 rocket launched NASDA's first satellite, called Kiku, in 1975. Although this was only an engineering test, it paved the way for an array of different applications including a network of comsats, a direct broadcast satellite TV system, weather satellites, and Earth and ocean observers. Recently, Japan has followed China in developing a recoverable satellite system, the Unmanned Space Experiment Recovery System (USERS).

N-1 LAUNCH
An N-1 rocket soars into the skies of Tanegashima in the mid-1970s. Its resemblance to the US Delta rocket is obvious.

BIOGRAPHY
TOYOHIRO AKIYAMA

The first Japanese person in space, Toyohiro Akiyama (b.1942) can also claim a place in the history books as the first journalist in space. His trip to Mir aboard Soyuz TM-11 in 1990 was paid for by the Tokyo Broadcasting System (TBS) network, and he made several live TV broadcasts during his time in space. Akiyama beat NASDA astronaut Mamoru Mohri into space after the launch of the Japanese-sponsored Spacelab-J Shuttle mission was delayed in the wake of the *Challenger* disaster.

SPACEPORT PANORAMA
JAXA's main launch site, at Tanegashima, is probably the world's most picturesque spaceport – although launches do have to be timed to fit around the local fishing industry.

DOCTOR ROCKET
Hideo Itokawa, musician, ballet dancer, and pioneer of the Japanese space programme, poses next to one of his experimental "Baby" rockets of the late 1950s.

Just as Europe's first venture beyond Earth orbit was the Giotto probe, so too Japan's Sakigake and Suisei 1986 missions to Halley's Comet paved the way for later missions to other worlds, though these missions met with mixed success.

Hiten, a technology test probe designed to relay signals from a small lunar orbiter, functioned well but was rendered useless when its partner mission, Hagomoro, failed. Nozomi, an orbiter intended to study the Martian atmosphere, failed to enter orbit around Mars after running short of fuel. And mystery still surrounds the success or failure of Hayabusa, which landed on the Near Earth Asteroid 25143 Itokawa in November 2003. The probe was supposed to take dust samples from the surface for return to Earth, but the sampling system is thought to have failed. However, it is possible that some asteroid dust may still be returned when the re-entry capsule is released in 2010. Meanwhile JAXA now has plans for a probe to Venus, and is involved in the BepiColombo mission to Mercury, a joint venture with ESA (see p.231).

Japan's astronauts

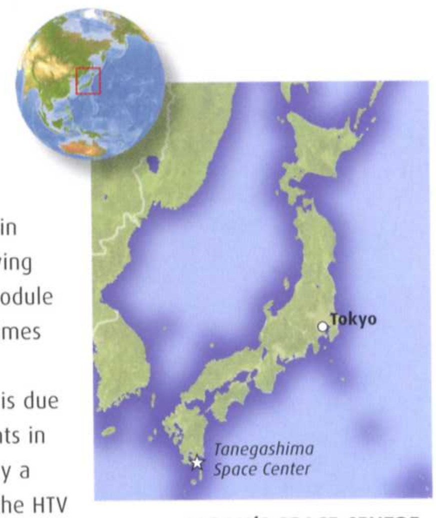
A number of Japanese astronauts and cosmonauts have reached orbit. NASDA had agreements with NASA for astronauts to fly as payload specialists on the Space Shuttle, but delays caused by the loss of the *Challenger* Space Shuttle meant that journalist Toyohiro Akiyama beat NASDA's specialists to become the first Japanese person in space (see panel, opposite). The first NASDA astronaut was Mamoru Mohri, who flew aboard the Japanese-sponsored Spacelab-J Shuttle mission in 1992. Despite the expected demise of the Space Shuttle, the future of Japanese manned spaceflight is assured – NASDA, and now JAXA, are partners in the International Space Station, supplying the complex Japanese Experimental Module (known by the acronym JEM or sometimes as Kibo, meaning "hope").

The largest module on the ISS, JEM is due for launch on three Space Shuttle flights in 2008 and 2009 and will be supplied by a new unmanned Japanese spacecraft, the HTV or H-II Transfer Vehicle. In the longer term, JAXA still harbours plans for a small rocket-launched spaceplane, although development of its H-II Orbiting Plane (HOPE) project was abandoned in 2003 after a decade of development, a victim of the reorganization of Japan's space agencies.

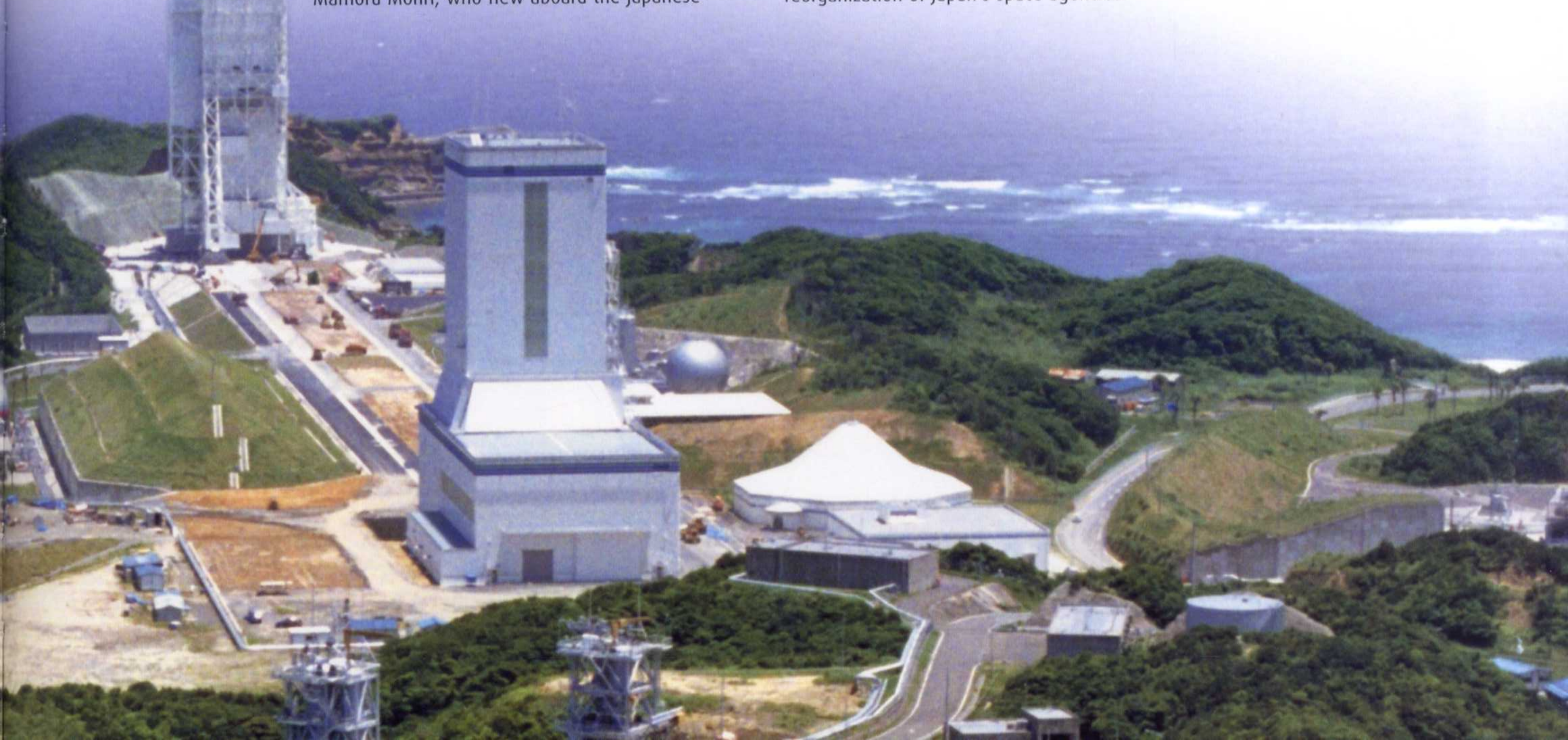
TECHNOLOGY

THE H-IIA ROCKET

JAXA's current workhorse launch vehicle is the H-IIA, a basic two-stage rocket, fuelled by efficient liquid hydrogen and oxygen, to which a variety of booster modules can be added if necessary, depending on the size of payload and its destination. The H-IIA was developed from NASDA's earlier H-II, which used similar fuels and had similar flexibility, but suffered from major reliability problems that brought the old Japanese space agency to a crisis. Since its first flight, in August 2001, the H-IIA has suffered only one failure and has begun to restore Japan's tarnished reputation in the launch market. JAXA is now developing the more powerful H-IIB, based on H-IIA's proven technology.



JAPAN'S SPACE CENTRE
Located on an island to the south of Kyushu in southern Japan, Tanegashima Space Center lies as close to the equator as possible, but is still at latitude 30°N.




发 射 流 程

Long March into space

Although China was the birthplace of the rocket, it was slow to become a modern space power. Yet it now has its own military programme and operates commercial launch vehicles and satellites.

SPACE PROPAGANDA
Just like the rival powers of the Space Race, China today presents its space programme as a symbol of national pride and superiority, as seen in posters like this one.

XICHANG CONTROL
Uniformed officers monitor a simulated launch from the control centre at Xichang Satellite Launch Centre, which is situated some 6km (4 miles) from the launch pad.

The catalyst for the formation of a national space programme in China dates back to the mid-1950s, when the recently established communist government welcomed the return of Tsien Hsue-shen from the USA (see panel, right). At the time, relations between the People's Republic of China and the Soviet Union were at their warmest, and an agreement signed in 1956 kick-started the Chinese missile programme by providing access to Soviet technology and expertise.

However, China was far from immune to the political machinations and dogmatism that often frustrated Soviet space scientists, and although missile development continued to be a priority, support for the space programme waxed and waned – particularly after relations with the Soviets began to deteriorate in 1960.

Nevertheless, in 1970 China launched its first satellite, Dong Fang Hong-1. This was an updated equivalent of Sputnik 1, orbiting the Earth while transmitting a recording of the communist patriotic song *The East is Red*. The launch vehicle was Tsien's own Chang Zheng ("Long March", abbreviated as either CZ or LM) design – which is still in use today, albeit in a different form (see panel, below). The success of the CZ rocket allowed China to enter the commercial launch market in 1985. Early customers included the comsat companies Asiasat in Hong Kong and Optus in Australia, as well as organizations in Sweden and Pakistan. Much of the Iridium satellite phone network has also been launched from China.

BIOGRAPHY

TSIEN HSUE-SHEN

Widely regarded as the founding father of China's space programme, Tsien Hsue-shen (b.1911) also played a key role in the early US space effort. Born and educated in China, he won a scholarship to study in the US in 1935. After moving to the California Institute of Technology in 1936, Tsien began work on experimental rockets. During the Second World War, he helped establish the Jet Propulsion Laboratory (JPL), but in 1950 he was arrested at the height of US anti-communist paranoia. After deportation to China in 1955, he did indeed join the Communist Party, leading the Chinese effort to develop ballistic missiles and launch vehicles.

A range of satellites

Since the first launch, China has put more than 50 satellites in the Dong Fang Hong (DFH) series into orbit – though, rather like the Soviet Cosmos satellite series, the DFH designation is used as a catch-all for a wide range of satellites, including remote-sensing missions, atmospheric studies, and a system of regional comsats also known as Chinasat.

A separate series of spacecraft is the FSW (a Chinese acronym for recoverable test vehicle). These satellites carry a capsule that can be used to return the results of satellite experiments to Earth, giving China an ability matched only by the US and Russia. Re-entry technology was developed as part of China's secret military satellite programme (in order to return photographic film from orbiting spy cameras), but it has also been used to return remote-sensing data and a variety of experiments from orbit.

In keeping with the Chinese attitude to their space programme, the technology was soon made commercially available, and the first customer to take advantage of the service was the French company Matra in 1987.

CHINESE SPACE FACILITIES
China's four major spaceports each specialize in a different type of launch. Geostationary satellites launch from Xichang or Wenchang, polar satellites from Taiyuan, and satellites with inclined orbits from Jiuquan.

TECHNOLOGY

LONG MARCH CZ ROCKETS

China's launchers were originally based on the DF-5 ICBM, but soon developed along their own path. The CZ-2 is a family of launchers built around a common core, to which a variety of boosters and extra stages can be added. Despite the introduction of the CZ-3, which uses more powerful liquid hydrogen and oxygen as propellants, the older rocket is still in use. Development problems for the CZ-3 culminated in a 1996 disaster when a rocket hit a village near its launch site. Following a thorough overhaul, the CZ-3 has operated flawlessly. A new launch vehicle, the CZ-6, is currently in development.

24 April 1970
China launches its first satellite, Dong Fang Hong-1 (DFH-1, sometimes also known as China-1), on a CZ-1 Long March rocket.

26 November 1975
The maiden flight of the CZ-2C rocket puts an FSW surveillance satellite, with a recoverable film capsule, into orbit.

8 April 1984
Dong Fang Hong-2 is launched by a CZ-3 rocket to become China's first geostationary comsat.

25 October 1985
China announces that it will make its launch vehicles and facilities commercially available.

7 September 1988
China launches its first weather satellite, Fengyun-1.

7 April 1990
China fulfils its first commercial contract, launching the Asiasat-1 comsat.

14 October 1999
The Ziyuan-1 remote-sensing satellite, a joint project of China and Brazil, is launched.

20 November 1999
China launches the first spacecraft in its new Shenzhou programme.

29 September 1962
The first non-superpower satellite, Canada's Alouette 1, is launched by a US rocket.

19 April 1975
India's first satellite, Aryabhata, is launched by the Soviet Union.

18 July 1980
India launches the Rohini 1B test satellite with its own SLV-3 rocket.

19 September 1988
Israel launches its first satellite, the prototype for a series of Ofeq reconnaissance satellites.

15 October 1994
India's polar satellite launch vehicle makes its first successful flight, launching the IRS P2 remote-sensing satellite.

18 April 2001
The first flight of India's Geosynchronous Satellite Launch Vehicle launches the GSAT-1 test satellite.

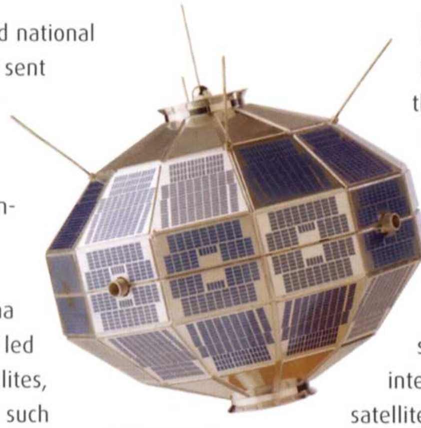
22 August 2003
A Brazilian prototype launch vehicle, the VLS-1 V03 explodes on the launch pad at Alcântara.

23 October 2004
Brazil successfully launches a VSV-30 rocket carrying a suborbital test satellite.

The spread of spaceflight

Since the 1960s, a handful of nations other than the major space powers have developed their own launchers and satellite programmes as commercial enterprise encourages access to space.

Several countries have developed national satellite projects that have been sent into orbit with the help of launch vehicles supplied by the more established space nations. Canada was the first non-superpower country to have its own satellite in orbit: Alouette 1 was launched by a US Thor-Agena B rocket in September 1962 and led to a whole series of similar satellites, as well as later national projects such as the Anik comsats.



ALOUETTE 1
The first Canadian satellite, designed to study the ionosphere layer of Earth's upper atmosphere, established a close relationship between NASA and Canada.

Other nations soon followed. NASA launched Italy's San Marco 1 atmospheric probe in 1964, Britain's Ariel 3 and Australia's Wresat in 1967, and Germany's Azur 1 to investigate the Van Allen Belts in 1969. A more ambitious German mission followed in 1974 – the first Helios probe, designed to orbit close to the Sun.

In the 1970s, the growth of satellite applications, and the establishment of specialist organizations and businesses to build satellite networks, broadened the launch market beyond national governments. By the 1980s, NASA had competition for these hungry customers – at first from ESA, but then from China and even the Soviet Union.

But, while most nations seem content to pay for their launches or enter into collaborations with the major space powers, a few countries have worked hard to develop their own launch capability.

India in space

India's space programme began in the mid-1960s with the foundation of ISRO, the Indian Space Research Organisation. ISRO developed the country's first satellites, including Aryabhata, launched by a Soviet rocket in 1975. India has tended to concentrate its satellite work in fields of national interest, producing remote-sensing satellites and comsats to aid the country's development. The first communications satellite, INSAT 1A, was launched in 1982 on a NASA Delta rocket, and India was also involved in the development of Direct Broadcast satellite television through the 1976 Satellite Instructional Television Experiment (SITE), which beamed educational programming to remote villages through a NASA satellite. Recently, ISRO revisited the concept with its EDUSAT mission, launched in September 2004. Indian remote-sensing satellites, meanwhile, have concentrated on hydrology and mineralogy, looking for vital water deposits and potentially valuable mineral resources.

Since the 1970s, ISRO has also worked to develop a series of SLV (Satellite Launch Vehicle) rockets. The four-stage, solid-fuelled SLV-3 launched its first payload, a test satellite called Rohini 1B, in 1980. For heavier payloads, a modified version called the ASLV (Advanced SLV) is assisted at launch by twin boosters.

The more powerful PSLV (Polar SLV) is a four-stage rocket with alternating solid- and liquid-fuelled stages. It made its first flight in 1994 and has become India's most widely used launcher. A Geosynchronous SLV (GSLV), able to lift heavier loads to higher altitudes, was introduced in 2001.

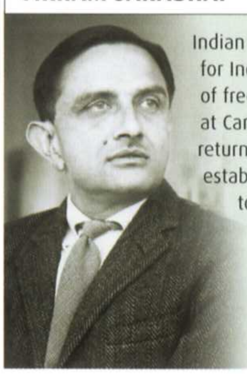
All ISRO vehicles are launched from the Satish Dhawan Space Centre, on the island of Sriharikota off India's southeastern coast. From here, rockets are launched over the Bay of Bengal at a latitude of about 14°N.

GEOSYNCHRONOUS SLV
India's latest launcher, the GSLV blasts off with EDUSAT aboard on 20 September 2004. The GSLV is a three-stage rocket with a solid first stage, a second stage based on traditional liquid fuels, and a new third stage fuelled by liquid hydrogen and oxygen.

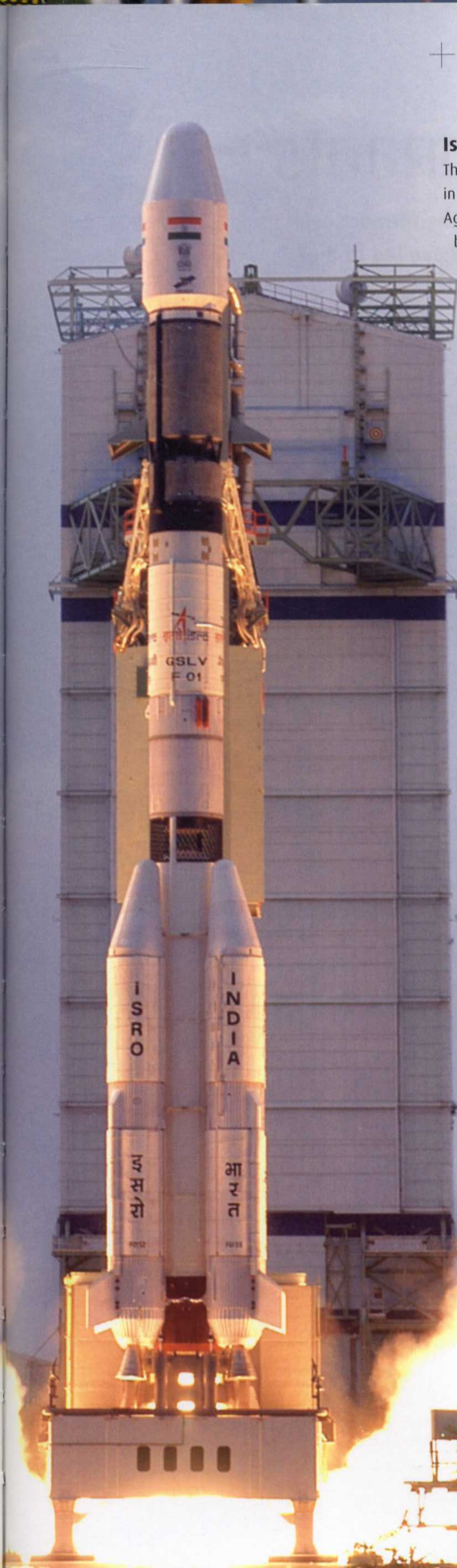
STACKING EDUSAT
The EDUSAT satellite is winched into place on top of its GSLV launch vehicle. The satellite provides interactive satellite TV-based education in remote areas of India.

BIOGRAPHY

VIKRAM SARABHAI



Indian physicist Vikram Sarabhai (1919–71) was largely responsible for India's early entry into the Space Age. Born into a wealthy family of freedom campaigners under the British Raj, Sarabhai studied at Cambridge University before and after the Second World War, returning to India after it gained independence in 1947. There he established the Physical Research Laboratory at Ahmedabad and rose to prominence in the Indian scientific community. Following the launch of Sputnik 1, he persuaded the Indian government to establish ISRO and then oversaw construction of the nation's first launch facilities and rockets, which were operational by 1963. He was later the driving force behind the Aryabhata satellite and the SITE project.



Israel in orbit

The Israeli space effort got underway in earnest in 1983 and is managed by ISA, the Israel Space Agency. Israel has developed a number of satellites, but is pragmatic about how they reach orbit. ISA's own launch vehicle, the Shavit, is based on the Jericho ballistic missile, solid-fuelled, and capable of launching only small payloads. Although it launched the first Israeli satellite, Ofeq 1, in 1988, and has since launched several more Ofeq reconnaissance satellites, other ISA satellites have been launched on European and Russian rockets. Israel has also signed a deal with India to launch spy satellites with the Indian PSLV.

Launching satellites from foreign sites gets around the difficulties caused by Israel's geographical location. Most satellites are launched eastwards, taking advantage of the speed boost provided by the Earth's daily rotation, but since Israeli rockets flying over (and potentially crashing in) other, mostly hostile, Middle Eastern countries would be politically dangerous, Shavit rockets are launched westwards over the Mediterranean. This means that they are effectively slowed down by the Earth's rotation, severely restricting the size of their payloads.

ISRAELI LAUNCHER
A Shavit rocket blasts skywards carrying Israel's Ofeq 5 spy satellite, in May 2002. Launches take place from the Palmahim Air Force Base south of Tel Aviv.

Brazil and beyond

The most recent nation to join the exclusive club of nations with their own space launch facility is Brazil. The Agência Espacial Brasileira (AEB) space agency has been developing its VLS-1 launch vehicle since its inception in 1994, but the road to space has not been easy. Two prototypes failed during test launches and a third exploded in August 2003 when one of its solid-fuel rockets ignited prematurely, killing 21 people and levelling the launch facility. Nevertheless, Brazil seems determined to become South America's first space power, bouncing back with determination to make its first suborbital space shot in October 2004.

While Brazil is likely to be sending satellites into orbit within a few years at most, which countries are most likely to follow in its footsteps? The answer may trigger a shudder of Space Race-era paranoia among many in the Western world, since it is Iran and North Korea who seem to be the two nations most committed to developing some kind of space-launch capability.

FIRST VLS-1 LAUNCH
The first prototype of Brazil's Veiculo Lancador de Satelites blasts off from the Alcântara launch centre close to the equator. The rocket was destroyed 65 seconds into its flight after veering off course due to a failed booster.

International astronauts

The vast majority of spacefarers have been citizens of the former Soviet Union or the United States, but politics and commerce have led to a variety of nations getting their own astronauts into space.

ILAN RAMON
Israel's first astronaut was killed returning to Earth during the Columbia *Space Shuttle disaster of 2003.*

PRINCE SULTAN AL-SAUD
Saudi Prince Sultan Al-Saud flew aboard Discovery *during the 1985 launch of the Arabsat-1B comsat.*

TAKAO DOI
Astronaut Takao Doi flew aboard the Space Shuttle Columbia *on mission STS-87 in 1997 and became the first Japanese person to perform a spacewalk.*

The Soviet Union was first to recognize the political capital to be made by taking passengers into space. Since the Soyuz spacecraft servicing their space stations had an operational life shorter than the typical station mission, visiting cosmonaut crews were used to bring fresh spacecraft to the station – arriving in a new Soyuz and departing aboard the older one. These brief visits offered the opportunity to take along cosmonauts from other nations – a programme the Soviets called Intercosmos.

At first, invitations were dictated by the politics of the Cold War – guest cosmonauts came from members of the Warsaw Pact alliance or from nations with which the USSR wanted to maintain good relations. Beneficiaries included Czechoslovakia (Vladimir Remek, 1978), Poland (Miroslaw Hermaszewski, 1978), Vietnam (Tuan Pham, 1980), and India (Rakesh Sharma, 1984). Although the operating life of the spacecraft improved with the Soyuz T and TM models, the duration of the long-term residencies also grew greater, so there was still a need to bring new spacecraft. The reintroduction of three-man flights with Soyuz T also meant that there was almost always a spare seat onboard.

From the mid-1980s onwards, as relations between the West and the Soviet bloc finally thawed, the range of guest cosmonauts increased to include passengers such as Helen Sharman from the UK (see p.217). The eventual collapse of the Soviet Union in 1991 and the appearance of a newly capitalist, impoverished Russia led to further expansion of the programme. Mir was "open for business", and foreign visitors, now paid for by their own governments, space agencies, or even private companies, jostled on the station with American astronauts. Towards the end of Mir's operating life, France paid for its spationaut Jean-Pierre Haigneré to stay on the station for a full six-month research tour.

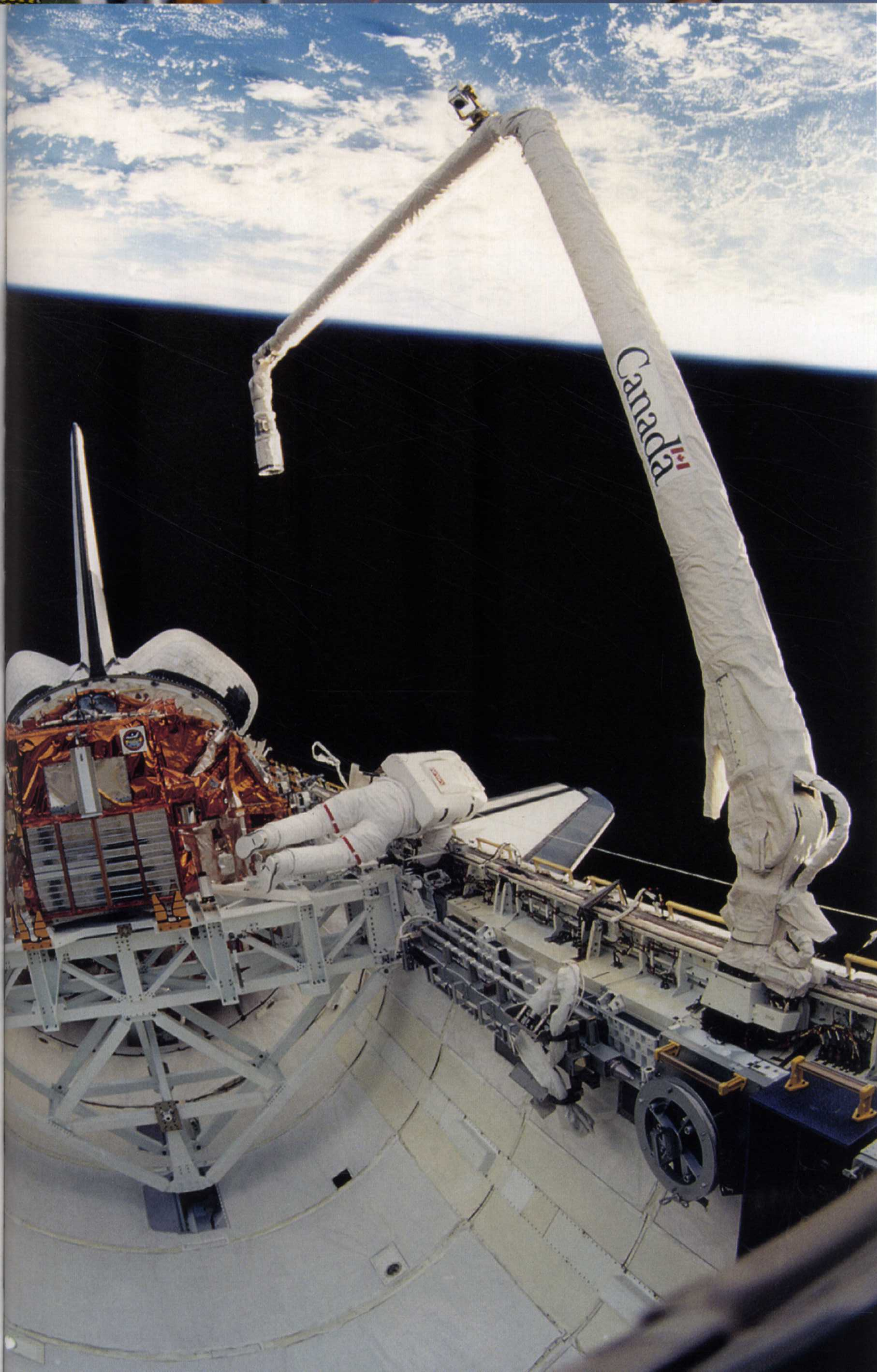
Shuttle visitors

NASA did not use the Space Shuttle for such overtly political purposes, but the nature of Shuttle crews meant that there were soon opportunities for foreign astronauts to take their place on board. While NASA's own pilots and mission specialists (professional astronauts) are US citizens or naturalized Americans, payload specialists are chosen in collaboration with whoever is sponsoring a mission, and international astronauts from various partner agencies also frequently join the crew. In this way, people from many countries have flown on the Shuttle during deployment of national satellites. The agreement to build Spacelab automatically assured ESA of a number of flights for its astronauts, and both Japan and Germany have sponsored additional Spacelab missions with their own astronauts.

NASA also has a special relationship with the Canadian Space Agency, which supplied the robot-arm systems for both the Space Shuttle and the ISS. As a result, Canada was invited to nominate several people to fly aboard the Shuttle, kick-starting its astronaut programme.

VLADIMIR REMEK
Czechoslovakia's first cosmonaut, and the first spacefarer from a non-superpower nation, Vladimir Remek (left) flew on the Soyuz 28 mission of 2–10 March 1978.

RAINBOW CREW
ISS expeditions are international affairs – the crew of the Soyuz TMA-8 handover flight, for example, consisted of (from left) Marcos Pontes (Brazil), Pavel Vinogradov (Russia), and Jeffrey Williams (United States).



2 March 1978
Vladimir Remek becomes the first non-Russian, non-American in space aboard Soyuz 28.

26 August 1978
East German Sigmund Jähn becomes the first German cosmonaut.

18 September 1980
Arnaldo Tamayo-Méndez becomes the first Cuban in space.

24 June 1982
Jean-Loup Chrétien of France becomes the first spationaut.

28 November 1983
Ulf Merbold becomes the first West German astronaut, aboard *Columbia*'s STS-9 flight.

3 April 1984
Rakesh Sharma becomes India's first cosmonaut.

5 October 1984
Marc Garneau becomes Canada's first astronaut with his flight aboard the Space Shuttle *Challenger* during STS-41G.

18 May 1991
Helen Sharman becomes the first Briton in space.

19 May 1996
Australian-born Andrew Thomas travels on the Space Shuttle *Endeavour*'s STS-77 mission.

CANADARM
The Canadian Space Agency's special relationship with NASA has allowed several Canadians to fly on the Space Shuttle. Here astronaut Chris Hadfield works in the Shuttle cargo bay during Endeavour's *STS-100 mission. The Canadian-built robot-arm (or Remote Manipulator System) is prominent in the foreground.*


NASA

AUGUST 2005: ROVER ON A RED PLANET
Turning the gaze of its panoramic camera downwards, the Mars Exploration Rover Spirit *photographs itself amid the dust of a Martian desert. After almost 20 months on the surface of Mars, the rover's solar arrays – providers of its energy and life – are still gleaming through only a thin veneer of dust.*

SATELLITES AND SPACEPROBES

THE SPACE AGE HAS TRANSFORMED our understanding of our own world and others. In 50 years, artificial satellites have gone from propaganda weapons to vital tools of humanity, watching over the Earth. They have gathered information on everything from hidden mineral deposits to long-term climate change, provided a new view of the Universe from beyond the atmosphere, and triggered a global revolution in communications that has helped to make the world a smaller place.

And while manned exploration of space has gone no further than our own Moon, our robot servants have gone much further. Spaceprobes have explored all the other major worlds that orbit the Sun, in addition to a number of the smaller objects that clutter the Solar System. They have ventured into environments that would quickly prove fatal to astronauts and to distant regions that would take decades for a manned mission to reach. The images and data they have sent back have not only revealed previously unseen worlds but also aided understanding of our own.

4 October 1957
The satellite age begins with the launch of Sputnik 1.

31 January 1958
Explorer 1 becomes the first satellite to return scientific data from orbit.

25 June 1959
The US launches its first spy satellite, Discoverer 4, though it fails to reach orbit.

7 August 1959
Explorer 6 returns the first television pictures from orbit.

1 April 1960
NASA launches the first successful weather satellite, TIROS 1.

7 March 1962
NASA launches Orbiting Solar Observatory 1, arguably the first astronomical satellite.

16 August 1964
Syncom 3, the first successful geostationary comsat, is launched.

23 April 1965
The Soviet Union launches Molniya 1-01, the first comsat with a highly elliptical orbit.

23 July 1972
NASA launches ERTS-1, the first remote-sensing satellite.

Orbiting the Earth

In the decades since Sputnik 1 first sent a simple radio signal back to Earth, artificial satellites have transformed not only our view of Earth and the wider Universe but also many aspects of everyday life.

As with many revolutionary technologies, it took some time for the full potential of the artificial satellite to be recognized. The wave of apprehension that greeted news of Sputnik 1 in the West was born of a fear that satellites might be used as weapons platforms to rain down missiles on a defenceless enemy. The military on both sides were also aware that satellites could act as spies in the sky, beyond the range of ground-based weapons. Indeed, many early US experimental satellites, such as Discoverer and Corona (see p.249), and some of the Soviet Cosmos series were in fact orbiting spy cameras.

It took longer for scientists to realize the potential of satellite-borne cameras for studying the Earth in general – an application known today as remote sensing. In fact, it was only when Gordon Cooper reported seeing roads and buildings from his Mercury capsule *Faith 7* in 1963 that NASA started to wonder about the possible applications.

Today, remote-sensing satellites are used to study many aspects of our planet's geology, oceanography, climate, and ecology. Looking the other way, astronomers have also made use of spaceflight – a location above the Earth's atmosphere holds obvious advantages for any instrument needing a clear view into deep space. One other predicted application was the communications satellite, or comsat – an orbital platform that bounces signals between distant places on Earth, overcoming the line-of-sight limitation of radio signals (see over). However, even enthusiasts would not have foreseen the communications revolution that comsats would trigger.

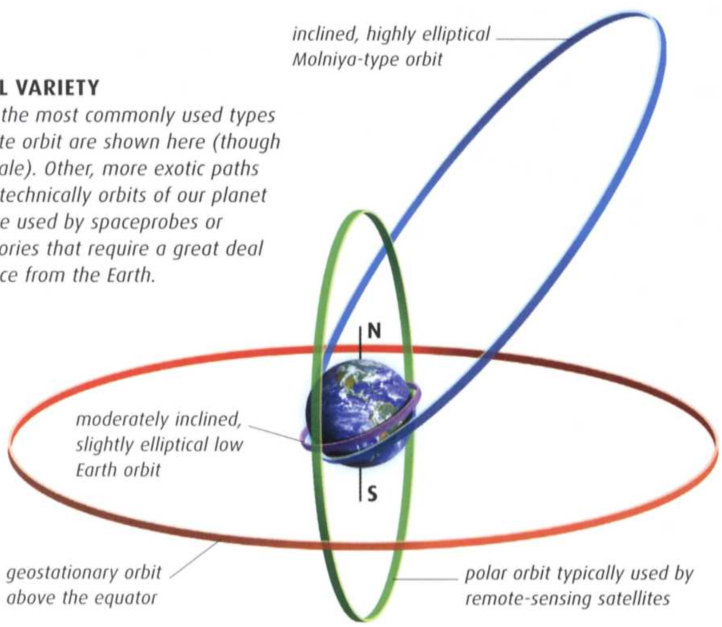
POLAR COSMODROME
Russia's northern cosmodrome at Plesetsk near Archangel is an ideal site for launching satellites into polar orbits and also into the highly inclined Molniya orbits used by Russian comsats.

Orbital mechanics

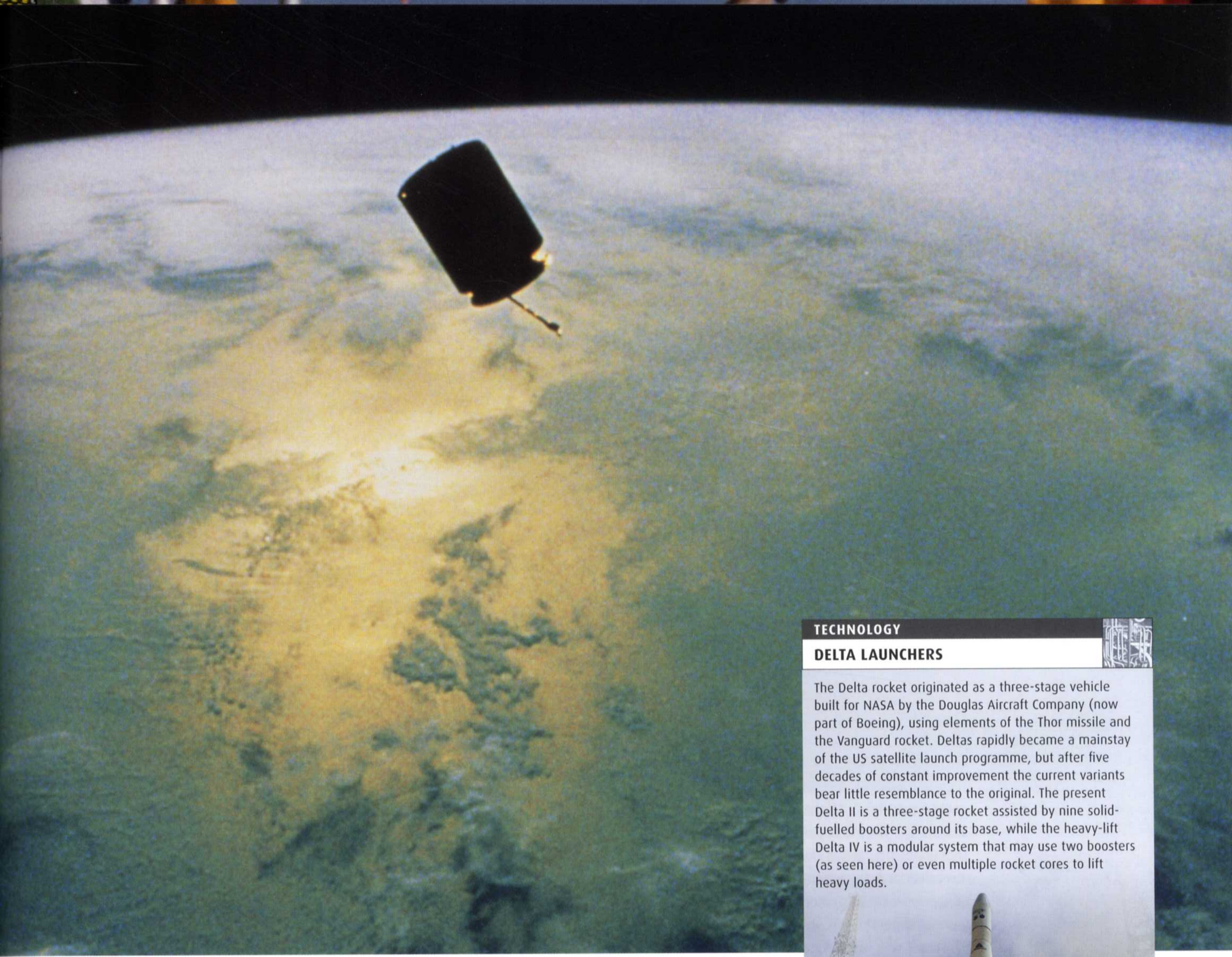
The shape of a satellite's orbit depends on its function. The further from the Earth a satellite is, the longer it takes to complete an orbit – not only because it has further to travel, but also because objects in orbit naturally move more slowly as they get further away from the object they are orbiting. One particularly useful orbit is the geostationary orbit first identified by Arthur C. Clarke (see p.246) and used by comsats and other craft that need to stay over a single spot on the Earth's surface. In geostationary orbit, a satellite sits precisely 35,786km (22,227 miles) above the equator, orbiting the Earth in 23 hours 56 minutes – the same time the planet itself takes to rotate. The satellite therefore stays over a single point on the equator, providing a fixed location in the Earth's skies.

However, most satellites fly much closer to our planet, in low Earth orbits (LEOs) a few hundred kilometres up, circling the world several times every day. This kind of altitude is close enough in for Earth-observing satellites to pick up fine details but far enough out to avoid drag from the upper

ORBITAL VARIETY
Some of the most commonly used types of satellite orbit are shown here (though not to scale). Other, more exotic paths are also technically orbits of our planet – they are used by spaceprobes or observatories that require a great deal of distance from the Earth.



BETWEEN ORBITS
Many satellites have their own integral rocket stages, called kick motors, to push them into their final orbit. Intelsat 603, launched into LEO by a Titan rocket in 1990, became stranded after its kick motor failed. It took a rescue mission from the Space Shuttle (see p.207) to finally get it to geostationary orbit.



atmosphere. For astronomy satellites, it is also high enough to avoid the atmospheric absorption of various types of radiation (see pp.250–57). Only space stations and large spacecraft typically orbit lower than this, skimming the upper atmosphere so that their orbits are unstable unless repeatedly boosted.

Very few orbits are circular – most are ellipses, dipping closer to the Earth on one side and rising higher above it on the other. Often the difference is minor and has no operational effect, but some projects (such as the Soviet Molniya satellites) use highly elliptical orbits and deliberately take advantage of the satellite's slower speed when further from the Earth. In Molniya's case, the shape of the satellites' orbits ensures that they move very slowly across Russian skies, acting as easily tracked communications platforms in northern regions, where equatorial comsats may not be visible.

Differing inclinations

Another important factor in a satellite's orbit is its inclination, or tilt relative to the equator. Although there are fuel advantages to launching satellites into orbits over the equator (see p.249), such orbits are useless for applications such as remote sensing, since the spacecraft will pass repeatedly over the same narrow strip of land and ocean. Instead, many types of satellite use inclined orbits that take them over high latitudes. Although the satellite only covers a narrow strip of land during each pass, the combined effect of repeated orbits and the Earth's daily rotation can gradually build up coverage of much of our planet's surface. The most extreme inclinations, known as polar orbits, allow a satellite to study the entire planet – but, just as some launch sites make it easier to reach equatorial and geostationary orbits, so only certain sites are suitable for polar launches.

TECHNOLOGY

DELTA LAUNCHERS

The Delta rocket originated as a three-stage vehicle built for NASA by the Douglas Aircraft Company (now part of Boeing), using elements of the Thor missile and the Vanguard rocket. Deltas rapidly became a mainstay of the US satellite launch programme, but after five decades of constant improvement the current variants bear little resemblance to the original. The present Delta II is a three-stage rocket assisted by nine solid-fuelled boosters around its base, while the heavy-lift Delta IV is a modular system that may use two boosters (as seen here) or even multiple rocket cores to lift heavy loads.

10 July 1962
Telstar, the world's first fully functional comsat, is launched.

14 February 1963
Syncom 1 is the first attempt to launch a geostationary comsat.

19 August 1964
Syncom 3 becomes the world's first truly geostationary comsat.

20 August 1964
INTELSAT is established to set up a global comsat network.

23 April 1965
The Soviet Union launches the first of its Molniya comsats.

30 May 1974
NASA's Applications Technology Satellite (ATS) 6 is launched. As the first satellite to offer direct broadcast to small receivers, it paves the way for satellite TV.

22 February 1978
Construction of the US Global Positioning System begins with the launch of NAVSTAR 1.

28 December 2005
Construction of Europe's Galileo Positioning System begins with the launch of a test satellite. The system is due to be operational by 2010.

Comsats and GPS

Orbiting communications relays and the Global Positioning System have had a huge impact on everyday life and spearheaded the commercialization of space.

Even before the dawn of the Space Age, it was clear that satellites had the potential to revolutionize communications, and the military were among the first to see the advantages. Telephone lines had limited capacity and were vulnerable to physical damage. Radio signals were fast but travelled in straight lines and so had limited range due to the curvature of the Earth (though there were attempts to bounce signals off the ionosphere, a layer of the upper atmosphere that reflects radio waves, with unpredictable results). In contrast, a satellite high in the sky could be used as a reflector, allowing signals beamed from one part of the world to be received anywhere else that the satellite was visible above the horizon. NASA's Echo project (see p.51) tested the idea with a simple reflector in orbit, while Telstar (see panel, opposite) was the first satellite with the capability to receive, amplify, and re-transmit signals.

SATELLITE PREPARATIONS
A Galileo GPS satellite is loaded into its protective shroud prior to launch on a Soyuz rocket with a Fregat upper stage. The satellite's manoeuvring motors are wrapped in gold foil.

Geostationary satellites

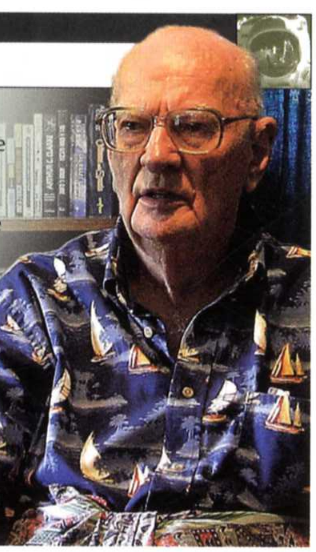
The ideal orbit for a comsat is the geostationary one noted by Arthur C. Clarke in 1945 (see panel, below, and p.244). From this point, a satellite maintains a steady position in the sky – it never rises or sets, and a receiver or transmitter aimed at it will not require adjustment. NASA pioneered the use of this orbit with its experimental series of Syncom satellites. Syncom 1 was lost before it could begin operations in February 1963, while Syncom 2, launched five months later, just missed the geostationary sweet spot but was close enough to prove the principle. The first truly geostationary communications satellite was Syncom 3, launched in August 1964. This mission had an immediate public impact, as the satellite was used to beam live pictures from the 1964 Tokyo Olympics in Japan to American broadcasters.

The benefits of comsats were so clear that even as the technology was being proved President Kennedy was calling for the establishment of an international organization to set up a global communications network. Nine months after Kennedy's death, the International Telecommunications Satellite Organization, or INTELSAT, came into being in August 1964 with 11 initial member states. It launched its first satellite, Early Bird, in April 1965, and over four decades, its membership grew to more than 100 nations, before it was privatized in 2001. Its satellite technology, meanwhile, advanced from the relatively primitive Early Bird to the 5,500kg (12,100lb) Intelsat 10. The success of INTELSAT opened the way for commercial companies to follow in its footsteps, and the organization also formed a template for similar efforts to develop regional comsat networks and

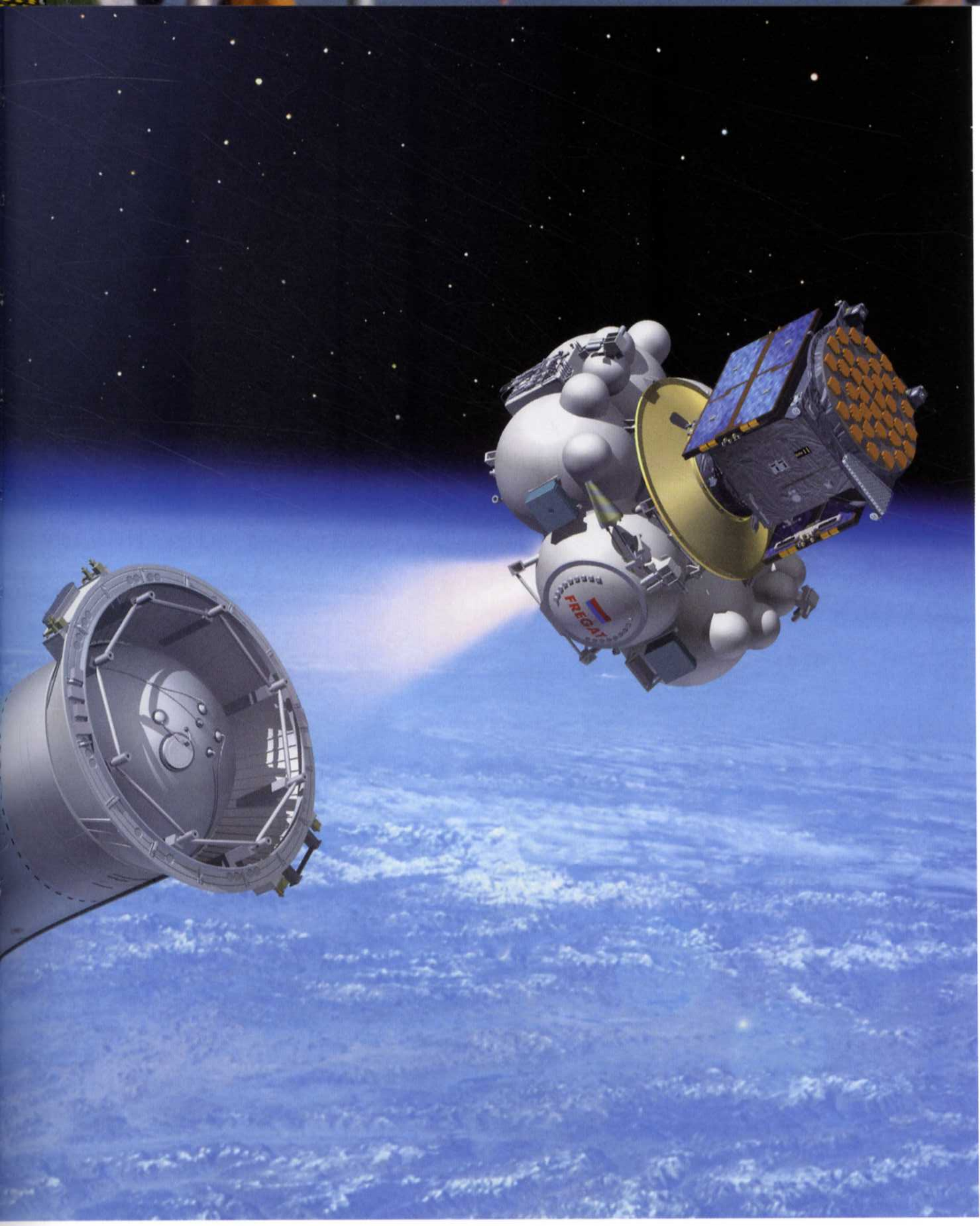
LAUNCHING GALILEO
This artist's impression shows the release of the first Galileo technology test satellite from its Fregat upper stage in December 2005. The antenna on top of the satellite is able to broadcast GPS signals across the whole of the Earth below it.

BIOGRAPHY

ARTHUR C. CLARKE



After serving in the RAF during the Second World War (working on the development of radar), Arthur C. Clarke (b.1917) became an active member of the British Interplanetary Society. From the 1950s, he found fame as a science-fiction writer and shrewd prophet of future technology – his most famous book is probably *2001: A Space Odyssey*. Clarke suggested the use of geostationary satellites as signal relays in a 1945 article for *Wireless World* magazine, and although he was not the first to note the usefulness of geostationary orbits, his (independent) proposal was the first to be widely noticed. However, Clarke did fail to predict the rise of microelectronics, believing at the time that his relays would have to be manned.



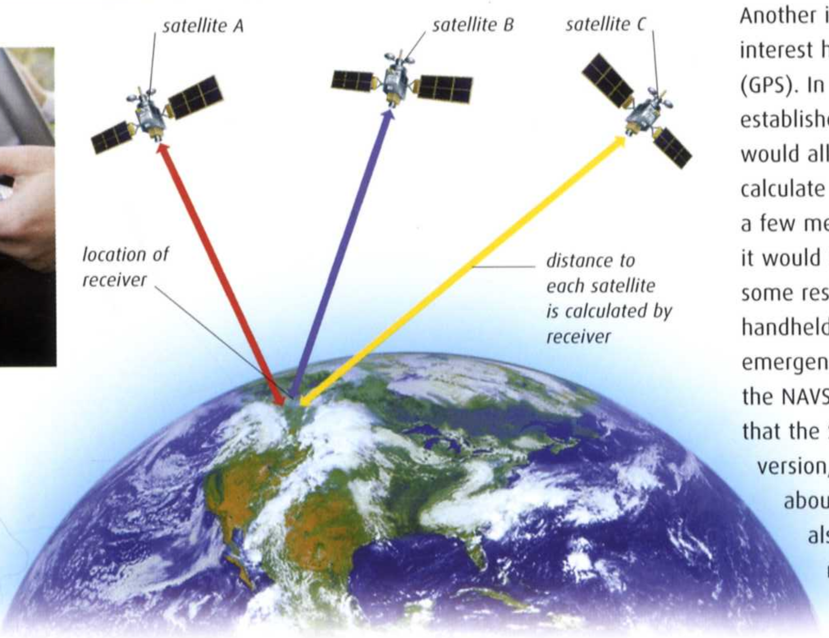
HISTORY FOCUS
TELSTAR

After various experiments with orbiting reflectors and taped transmissions from orbit, Telstar became the world's first true communications satellite when it was launched by a Delta rocket on 10 July 1962. Built at Bell Telephone Laboratories in the United States, the satellite was part of a joint programme developed by Britain, France, and the US. Telstar had the ability to receive signals from the ground, amplify them (using power from the solar cells on its spherical surface), and retransmit them through the horn antennae around its equator. It went into service as soon as it reached orbit, successfully transmitting television signals, phone calls, and even faxes across the Atlantic.

other satellite applications. One well-known example is the Iridium network, a series of 66 satellites that offers direct satellite communications for anyone with a suitable telephone. Iridium is widely used by the US military as well as commercial customers.

Navigation from space

Another important spin-off from initial military interest has been the Global Positioning System (GPS). In the 1970s and 1980s, the United States established a satellite network called NAVSTAR that would allow anyone using a suitable receiver to calculate their location anywhere on Earth to within a few metres. In 1983, President Reagan announced it would be made available for civilian use, with some restrictions. Today, applications range from handheld devices to in-car navigation systems and emergency rescue beacons. Since the primary use of the NAVSTAR system was military, it is little wonder that the Soviet Union chose to develop its own version, called GLONASS, in the 1980s. Concerns about overdependence on a US military system also led the European Union to devise its own rival civilian system, called Galileo, which should be complete by 2010.

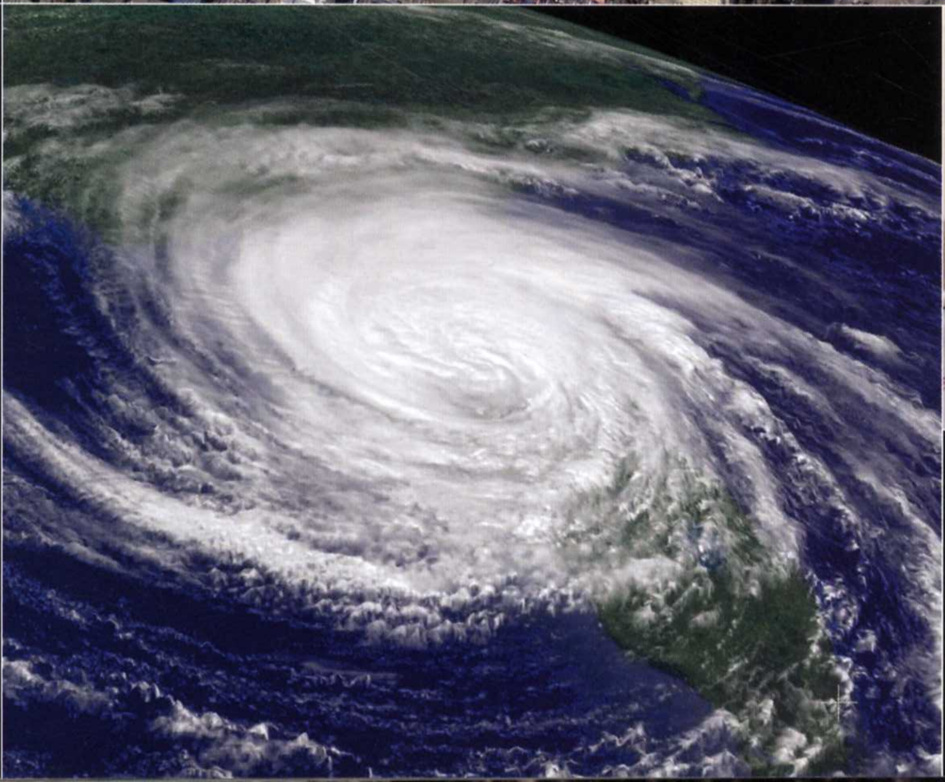


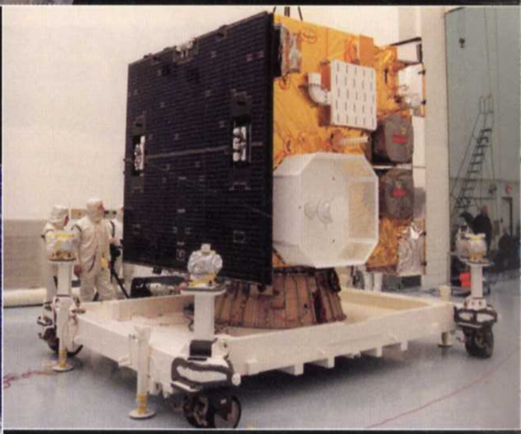
TRIANGULATION FOR GPS
The details of GPS are complex, but the principle is simple – by calculating the time taken for signals from a number of different satellites to reach it, the receiver works out its distance from each one. It then uses a detailed model of the satellite orbits to calculate its location on Earth – a process called triangulation.

COMMERCIAL SPY
Ikonos-2 is the world's first commercially operated reconnaissance satellite. Its operator GeoEye uses it to provide high-resolution multispectral and true-colour (panchromatic) images such as this one of San Francisco (right).

TSUNAMI WATCH
In December 2004, a massive Tsunami laid waste to coastlines around the Indian Ocean. Landsat 7 captured an image (above) of the waves breaking at Devi Point on the eastern shoreline of India.

HURRICANE WARNING
From high above the Earth, GOES satellites send back images to assist in weather forecasting, climate science, and storm preparation. In September 2004, GOES-12 monitored Hurricane Jeanne above the Gulf of Mexico.





GOES-L READY FOR FLIGHT
Weather satellites of the long-running Geostationary Operational Environmental Satellite (GOES) series (above) are built by NASA for NOAA, the National Oceanic and Atmospheric Administration.

Watchers from above

Early satellites looked down at Earth to monitor the weather or collect military intelligence, but remote-sensing orbiters developed since the 1970s have probably done most to change the way we look at our world.

The first spy satellites were launched in the earliest days of the Space Race in the late-1950s. American Discoverer and Corona vehicles, and various Soviet Cosmos satellites, carried automatic cameras onboard, usually attached to downward-pointing telescopes. Exposed film from these cameras then had to be physically returned to Earth for processing.

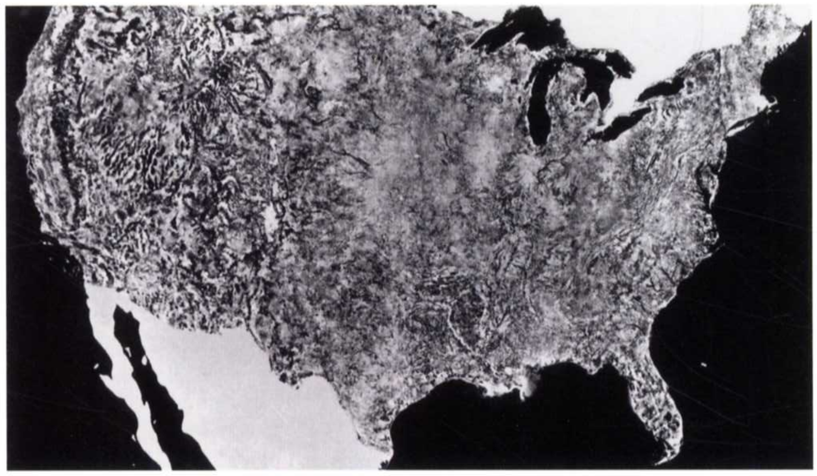
Alternatives were pioneered by the US Satellite and Mssile Observation System (SAMOS) programme, and the Soviet Luna 3 spaceprobe. In 1959 Luna 3 developed its film onboard, then scanned the images and sent them back electronically (see p.53). The SAMOS satellites of the 1960s used television cameras, recording pictures over foreign territory and sending them back to Earth over the US. But for most intelligence purposes, only the highest resolutions will do – and since electronic cameras could not hope to match film until the 1980s, re-entry satellites remained in use by the military for some time.

Other applications for satellites viewing the Earth did not generally require such high-quality images and so relied much sooner on data transmitted from orbit. One obvious use for such satellites was for meteorology – the first experimental NASA weather satellite was TIROS (Television and Infrared Observation Satellite) 1, launched in April 1960. Early weather satellites remained close to the Earth in polar orbits, photographing one strip of the planet at a time – the first geostationary weather satellite, able to keep an entire hemisphere of Earth in constant view, was not launched until 1974.

Earth remote sensing

The full potential of satellites for Earth observation became clear only when early astronauts reported seeing surprising detail from high altitudes. The Earth-orbiting Apollo 9 mission carried experiments to test ways of exploiting the view from orbit, including the first use of multispectral imaging (see panel, right). Soviet cosmonauts carried out similar experiments onboard the Salyut space stations, as did the astronauts aboard Skylab.

NASA launched its first satellite dedicated to these new remote-sensing techniques in 1972. Satellites in the Earth Resources Technology Satellite (ERTS) series was renamed Landsat after the launch of Landsat 2 in 1975, and the programme continues today.



THE BIG PICTURE
An early display of remote sensing's potential was this giant, cloud-free photographic map of the contiguous United States, assembled in 1972 from 595 satellite images by the US Department of Agriculture. ERTS 1's orbit allowed it to take images from a constant altitude of 912km (560 miles) in the same lighting conditions.

The Landsats are among the most successful of remote-sensing satellites, but many others have been developed. ESA and the Soviet Union launched their own equivalents, but as scientists have found new ways to probe our planet's properties, many more specialized missions have been launched.

Today's satellites monitor every aspect of the Earth, from air temperature to ocean circulation, and from wave height to wind speed. Satellites equipped with spectrometers can analyze radiation emitted or reflected from the ground below, revealing everything from crop usage to buried water and mineral resources. Synthetic aperture radar (SAR) can gather detailed information about the landscape (see p.267) and microwave radars can even penetrate the topsoil to reveal underground features.

1 April 1960
NASA launches TIROS 1, its first weather satellite.

12 August 1960
The film capsule from US spy satellite Discoverer 13 is successfully recovered.

28 July 1962
The Soviet Union launches its first successful Zenit spy satellite under the codename Cosmos 7.

3 March 1969
Apollo 9 carries an experimental multi-spectral imager into orbit.

June 1971
The first civilian Soviet space station, Salyut 1, studies the potential of multispectral imaging.

23 July 1972
ERTS 1, the first remote-sensing satellite, is launched.

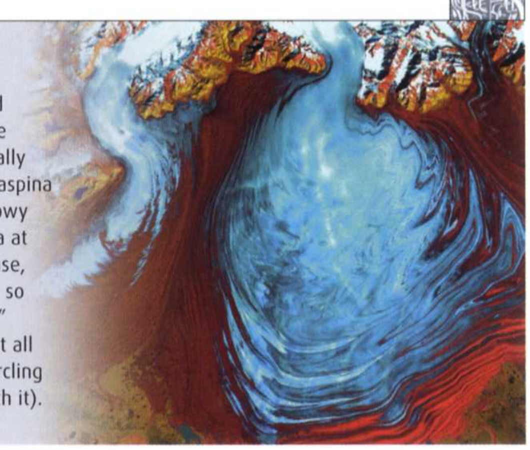
17 May 1974
NASA launches SMS 1 (Synchronous Meteorological Satellite), the first geostationary weather satellite.

25 June 1974
The first successful military space station, Salyut 3, carries a large reconnaissance camera onboard.

28 June 1978
NASA's Seasat carries the first synthetic aperture radar into orbit.

TECHNOLOGY

MULTISPECTRAL IMAGING



The technique of multispectral imaging is simple but powerful – a camera fitted with a series of filters takes images of the same area in specific wavelengths (colours) of visible light and sometimes in infrared or ultraviolet light. When the images are compared or combined, features and properties that are normally invisible can be seen and analyzed – as in this map of the Malaspina Glacier in Alaska, which in visible light is simply lost in the snowy landscape. Often researchers will want to revisit the same area at intervals in order to reveal changes in the landscape. In this case, it is important that all the images are lit from the same angle, so remote-sensing satellites frequently occupy "Sun-synchronous" polar orbits: the satellite maintains its orientation to the Sun at all times (in other words, its orbit progresses slightly each day, circling the Earth once every year, while the Earth rotates daily beneath it).

1966

Astronomy in orbit

The arrival of the Space Age provided huge new opportunities for astronomers – finally they could send instruments above the Earth's atmosphere for a clear view of the Universe.

8 April 1966
NASA launches OAO-1, but it fails in orbit.

4 July 1968
NASA launches RAE-1, which deploys a cross-shaped 450m (1,500ft) antenna in orbit.

7 December 1968
The Orbiting Astronomical Observatory 2 is launched and begins ultraviolet observations.

July 1969
Gamma-ray bursts are first observed by US Vela satellites.

12 December 1970
SAS-1 (Uhuru), the first X-ray detector in space, is launched.

15 November 1972
NASA launches SAS-2, the first dedicated gamma-ray observatory.

12 November 1978
The Einstein satellite (HEAO-2) becomes the first imaging X-ray telescope in orbit.

25 January 1983
IRAS, the first infrared space telescope, is launched and operates for ten months.

Astronomers have always been frustrated by the Earth's atmosphere – even on a clear night, turbulent air currents can distort and blur telescope images. In the 19th and 20th centuries, their frustration grew as they learned that visible light was just a small part of a spectrum of electromagnetic waves ranging from very long radio waves to ultra-short, high-energy gamma rays – and that the atmosphere did a thorough job of blocking out nearly all of them.

So when captured V-2 rockets became available at the end of the Second World War, astronomers were eager to utilize them to take a look at the Universe from beyond the atmosphere. Rocket-borne detectors soon revealed that space was full of exotic radiations – ultraviolet radiation from the Sun was discovered in 1946, and solar X-rays in 1949. Radio waves from the Milky Way (the plane of our galaxy) had previously been discovered from the ground in 1932 by American engineer Karl Jansky.

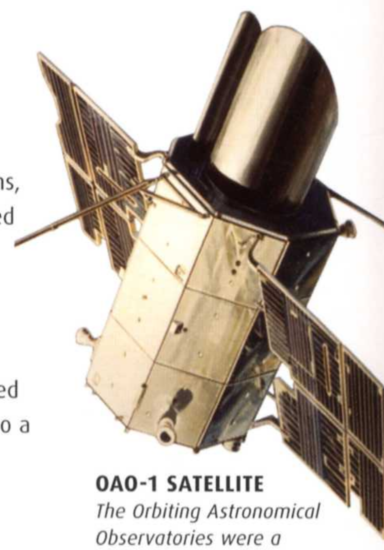
Early satellites added to these discoveries, sometimes unexpectedly. Long-wavelength radio waves (thought to originate in clouds of cool dust and gas) were revealed in the early 1960s by satellites that were actually built to study the Earth's ionosphere. The first X-ray source beyond the Solar System (now suspected to be a black hole) was identified in 1962. Dedicated observatories soon followed, though the earliest, such as the Orbiting Solar Observatory (OSO) series, were intended to reveal more about the Sun rather than target more distant objects. The first successful satellites designed to look further afield were NASA's Radio Astronomy Explorer (RAE) missions, launched from 1968 onwards. The RAEs recorded radio waves from the Sun, Jupiter, and various sources elsewhere in our galaxy.

The first X-ray astronomy satellite was NASA's Small Astronomy Satellite (SAS) 1, also known as Uhuru, launched in 1970. This revealed X-ray sources scattered across the sky and led to a variety of later missions.

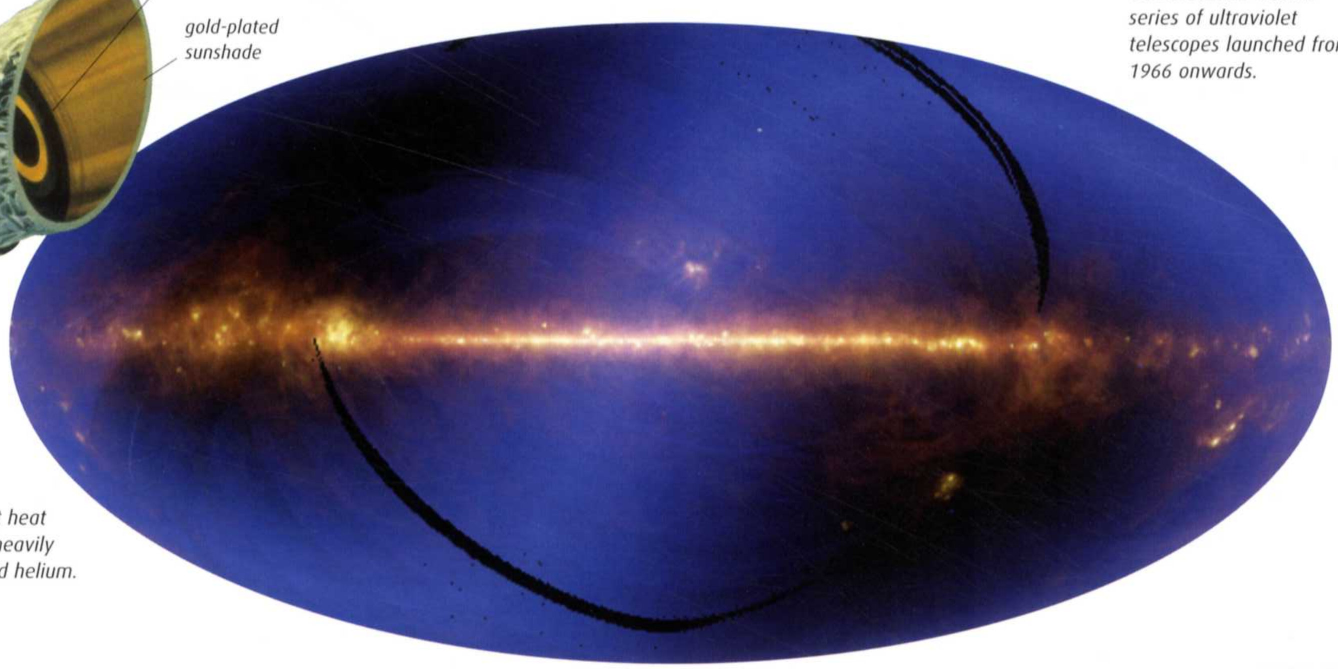
HISTORY FOCUS

OBSERVATORIES ON THE MOON

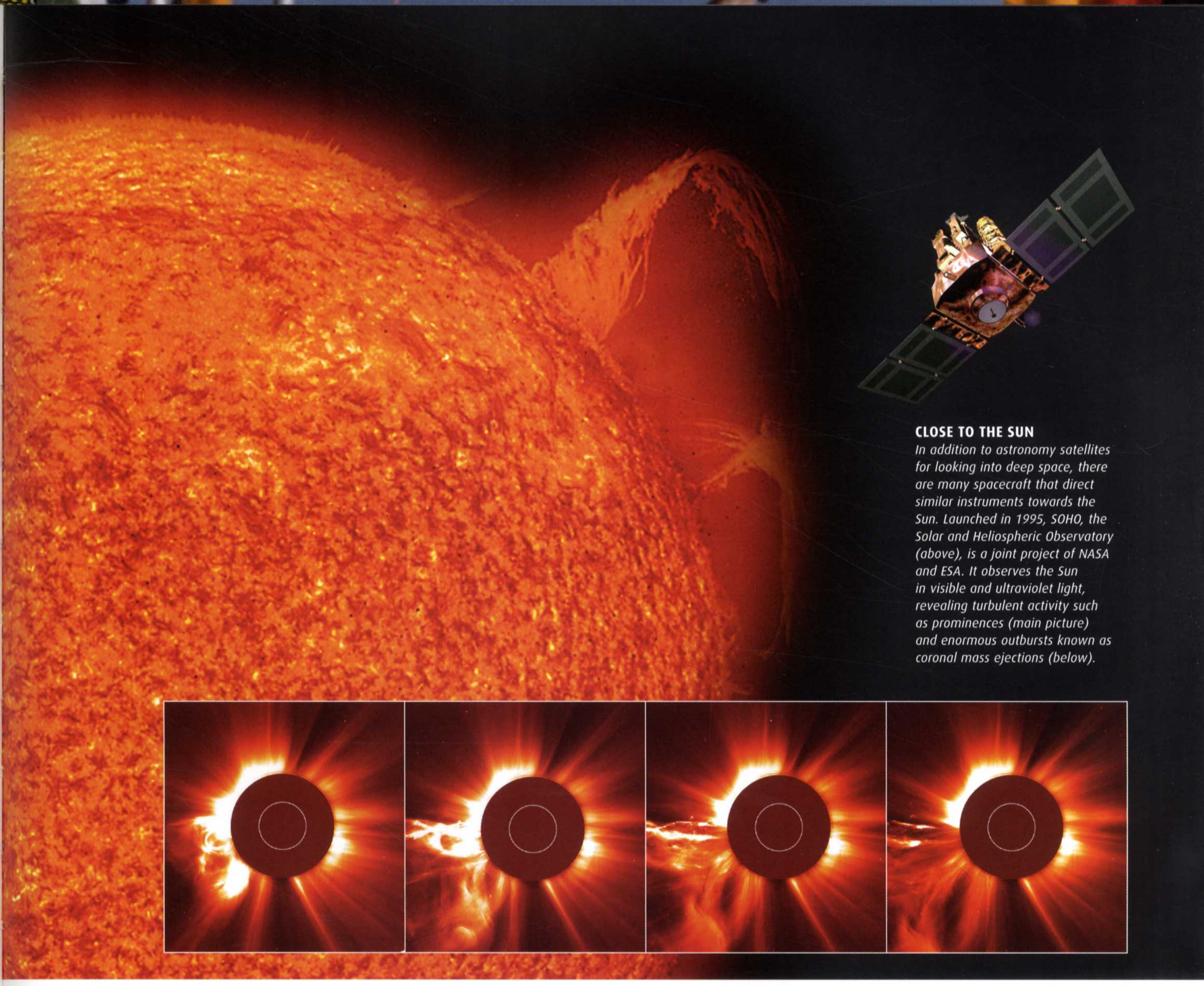
Before the microelectronics boom of the 1970s, it seemed as though many satellite instruments, including those for astronomy, would be impossible to automate. As a result, astronomy looked like being one of the main roles of any future moonbase. Operating under a long day-night cycle and in a thin atmosphere, a telescope on the Moon could see clearly into deep space – with protection from the surface glare, it could even operate when the Sun was above the horizon. A lunar observatory would also make it possible to construct larger telescopes than any that could be put in orbit. Today, advances in electronics and ingenious design have overcome many limitations of orbiting telescopes, but radio astronomers in particular still dream of building a telescope on the lunar far side.



OAO-1 SATELLITE
The Orbiting Astronomical Observatories were a series of ultraviolet telescopes launched from 1966 onwards.



IRAS SATELLITE
Launched in 1983, the Infrared Astronomical Satellite (IRAS, above) was the first orbital telescope to study the sky in the infrared (right). In order to pick up faint heat radiation from the sky, it was heavily insulated and cooled with liquid helium.

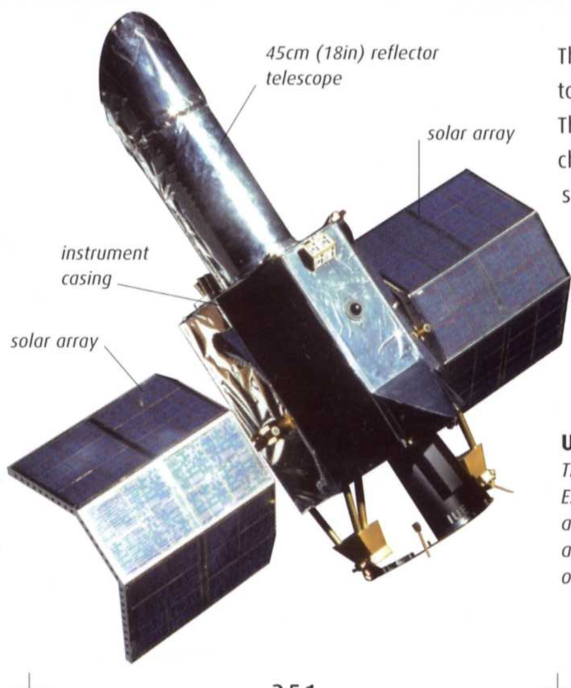


CLOSE TO THE SUN
In addition to astronomy satellites for looking into deep space, there are many spacecraft that direct similar instruments towards the Sun. Launched in 1995, SOHO, the Solar and Heliospheric Observatory (above), is a joint project of NASA and ESA. It observes the Sun in visible and ultraviolet light, revealing turbulent activity such as prominences (main picture) and enormous outbursts known as coronal mass ejections (below).

Another new field of astronomy opened when US Vela spy satellites, designed to look for evidence of nuclear testing on Earth, detected bursts of gamma rays from deep space. Their existence was confirmed in 1972 by SAS-2, which also found gamma-ray sources in the remnants of exploded stars. ESA's Cos-B gamma-ray satellite of 1975 was followed by several French experiments carried aboard Soviet spacecraft and space stations.

Beyond the blue, within the red

The first successful ultraviolet satellite was Orbiting Astronomical Observatory (OAO) 2. Launched in 1968, it studied the ultraviolet properties of thousands of stars, as well as objects such as comets and galaxies. Other ultraviolet observatories soon followed.



The last major area of the electromagnetic spectrum to be explored from space was the infrared. The nature of this heat radiation creates unique challenges – since the telescope itself is an infrared source, it must be cooled to very low temperatures to avoid swamping the weak infrared light from stars and other objects. The challenges were first overcome with the Infrared Astronomical Satellite (IRAS), a joint British, American, and Dutch mission launched in 1983.

ULTRAVIOLET OBSERVATORY
The highly productive International Ultraviolet Explorer (IUE), a joint venture between NASA, ESA, and the United Kingdom, operated for 18 years and was the first satellite that astronomers could operate from the ground in real time.

The Hubble Space Telescope

The first large orbiting telescope to study the Universe in visible light, the Hubble Space Telescope (HST) has revolutionized our view of the cosmos, answering some key questions in modern astronomy and raising new ones.

25 April 1990
The Space Shuttle *Discovery* deploys the Hubble Space Telescope into low Earth orbit.

December 1993
The Space Shuttle *Endeavour* recaptures the HST for a ten-day servicing mission as well as the installation of the COSTAR corrective optics system.

February 1997
A second servicing mission by *Discovery* fits new instruments, including an infrared detector.

May 1999
The HST Key Project, an effort to refine understanding of the age and scale of the Universe by measuring the brightness of distant stars, is completed.

December 1999
A third servicing mission is carried out by *Discovery* after the failure of three of the telescope's six steering gyroscopes.

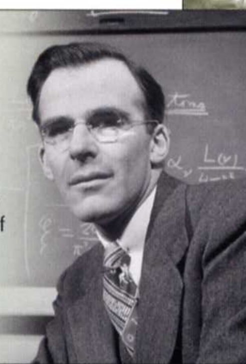
March 2002
Servicing mission 3B, by *Columbia*, installs a new camera and revives the infrared detector with new coolant. It also replaces the solar arrays for a second time.

Astronomers have long been aware of the benefits of a telescope in space. Visible light is one of the few types of radiation that pass through our atmosphere relatively unscathed, but its passage through the air to even the highest mountaintop observatories is still affected by blurring and distortion. A telescope above the atmosphere would be immune to these problems. While Earthbound telescopes might have larger mirrors and therefore greater light grasp (the theoretical ability to see fainter objects), an orbiting observatory would see everything in pin-sharp detail.

The orbiting Hubble Space Telescope was championed by Lyman Spitzer (see panel, right). It finally received funding in 1977 and was scheduled for an October 1986 launch when tragedy struck the Space Shuttle *Challenger* (see pp.202–203). Although the remaining Shuttles returned to flight in late 1988, a slot could not be found to deploy the HST until *Discovery*'s STS-31 mission of April 1990.

BIOGRAPHY

LYMAN SPITZER



American astronomer and physicist Lyman Spitzer Jr. (1914–1997) was the first person to suggest putting an optical telescope into Earth orbit in his 1946 paper *Astronomical Advantages of an Extra-Terrestrial Observatory*. Already a rising star of astrophysics before the Second World War, he became head of his department at Princeton University aged only 33. His interests ranged from interstellar gas and dust to plasma physics and nuclear fusion. After leading the design of NASA's Copernicus ultraviolet telescope (see p.250), he was asked in 1965 to chair a committee planning a "large space telescope". He did a great deal to convince Congress and sceptical scientists to back the project.

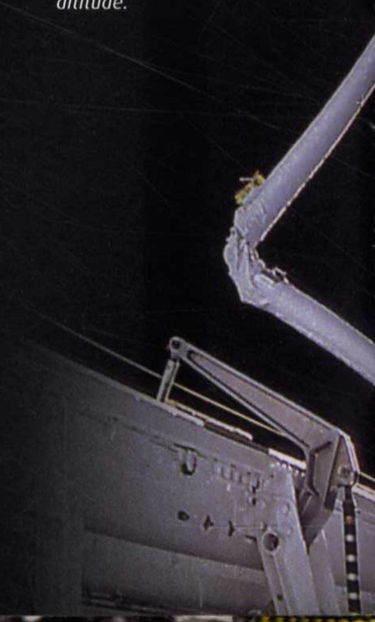
Teething troubles

The optical design of the HST was similar to many Earthbound telescopes, using a series of mirrors to bend light to a focus behind the large primary mirror, in any of four instrument modules. The initial instrument suite incorporated five instruments (two cameras, two spectrographs for analyzing light, and a photometer for measuring the precise brightness of objects). The HST was always designed for a long life, with occasional visits from the Shuttle to perform repairs and install new instruments. This was just as well, because when scientists at Baltimore's Space Telescope Science Institute began to put the telescope through its paces, they discovered that the primary mirror had a minute flaw in its shape – and as a result, all Hubble's images were blurred.

While the HST was not entirely crippled by the problem, it was a huge embarrassment. Fortunately, a way was found to compensate for Hubble's short sight (see panel, opposite). A rescue mission in December 1993 was an outstanding success, paving the way for three more servicing missions.

Since the repair, the HST has been one of the world's most productive scientific instruments, making countless observations and helping to solve many conundrums about the Universe. It has also been a source of good publicity for NASA, its beautiful, spectacular, and sometimes profound images frequently making the headlines. Such is the telescope's popularity that in 2006, NASA gave in to public pressure and lifted its own ban on non-ISS Shuttle flights, scheduling one final servicing mission for 2008. This may allow the HST to run until its replacement is ready in the mid-2010s.

ANATOMY OF A SPACE TELESCOPE
Light entering the HST is reflected off a convex primary mirror, which bounces rays back on converging paths to a smaller secondary mirror. From here, it is folded back again, through a hole in the centre of the primary and brought to a focus at the instruments.



RELEASED IN ORBIT
Discovery's robot arm delicately places the HST in orbit 612km (380 miles) above the Earth during initial deployment in April 1990. Placing the telescope well above the atmosphere meant taking the Shuttle to an unusually high altitude.

LOOKING BACK IN TIME
The Hubble "Deep Fields" are among the HST's most iconic images – panoramas produced by pointing the telescope at the same patch of sky for several days. They show galaxies so distant that their light started its journey to us billions of years ago.

TECHNOLOGY

FIXING HUBBLE

Since there was no way to replace or repair Hubble's original primary mirror in orbit, engineers and scientists devised an optical box of tricks called the Corrective Optics Space Telescope Axial Replacement (COSTAR). This used ten precisely ground mirrors to adjust the path of light through the telescope and bring it into focus. It was built to slot into one of Hubble's existing instrument bays, diverting corrected light back into any of the other three. With COSTAR in place, the improvement in Hubble's images was spectacular.

Before correction

After correction

HUBBLE HIGHLIGHTS

In well over a decade of operation, the Hubble Space Telescope has captured some of the most spectacular images of the cosmos ever seen. These distant vistas show objects and events that our spacecraft and probes may never reach, yet with Hubble's help, we can still explore them.

The Crab Nebula (left) is all that remains of a once-brilliant star – it detonated in a supernova explosion almost a thousand years ago, and since then its shredded remnants have been expanding outwards to form a gas bubble in space. Another type of bubble is the Cat's Eye Nebula (right) – the outer layers of a less violent star that is nearing the end of its life and blowing most of its material away into space. Much further away lie colliding galaxies such as the Antennae (above). The HST's snapshots capture only an instant in a process that lasts millions of years and which will ultimately create new generations of stars.

1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

Great observatories

Since 1991, NASA has put a series of astrophysical instruments into orbit, complementing the Hubble Space Telescope (HST) with observations of the Universe made by collecting radiation from beyond the visible spectrum.

5 April 1991
The Compton Gamma Ray Observatory (CGRO) is deployed into low Earth orbit from the Space Shuttle *Atlantis*.

19 September 1994
CGRO makes the surprising discovery of gamma rays generated by Earth's thunderstorms.

23 July 1999
The Chandra X-ray Observatory is deployed from *Columbia*.

4 June 2000
For safety reasons, CGRO is deliberately taken out of orbit while NASA can still control its re-entry.

June 2000
NASA scientists announce Chandra's discovery of rings in the Crab Nebula supernova remnant.

September 2001
Scientists announce Chandra's detection of X-ray flares from a giant black hole at the centre of the Milky Way.

25 August 2003
The Spitzer Space Telescope is launched on a Delta rocket.

22 March 2005
NASA announces Spitzer's detection of light from planets around other stars.

During the 1980s, many astronomers realized the benefits of a series of parallel observatories that could study the sky at different wavelengths. Optical (and near-ultraviolet) images from Hubble could then be complemented by simultaneous observations from other telescopes, revealing how the visible appearance of an object related to its changing properties in other wavelengths. This was the origin of the Great Observatories Program, a series of four satellites (including the HST) to observe the Universe in visible and near-ultraviolet light, gamma rays, X-rays, and the infrared.

The high-energy Universe

The Compton Gamma-Ray Observatory (CGRO) was launched in 1991 and set a new record for a Shuttle payload, weighing in at 17,000kg (37,400lb). Onboard were four instruments, each measuring different gamma-ray properties and "tuned" to detect gamma rays of different energies.

Gamma rays pass through most materials and so cannot be focused by reflectors in the same way as other radiations. In order to work out the source of rays, CGRO's imaging telescope used a unique solution – stacking layers of detectors on top of one another and measuring the sequence in which they recorded gamma rays passing through them. The telescope was named after Arthur Compton, the physicist who discovered the "Compton scattering" process on which all its detectors relied.

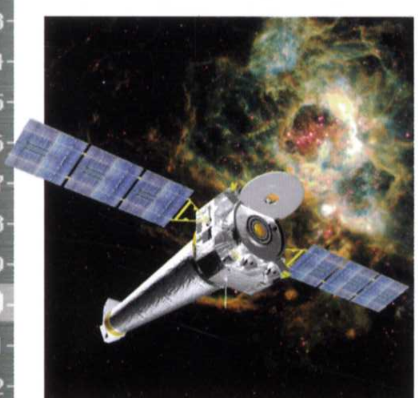
In nine years of operation, CGRO detected more than 400 new gamma-ray sources (ten times the number previously known), associated with some of the most bizarre objects in the Universe. Despite this remarkable success, NASA deliberately brought the mission to an end in 2000. A failure in one of CGRO's three gyroscopic stabilisers meant that if another had failed ground controllers would have been unable to guide the massive spacecraft to re-entry over an unpopulated area.

X-ray observations

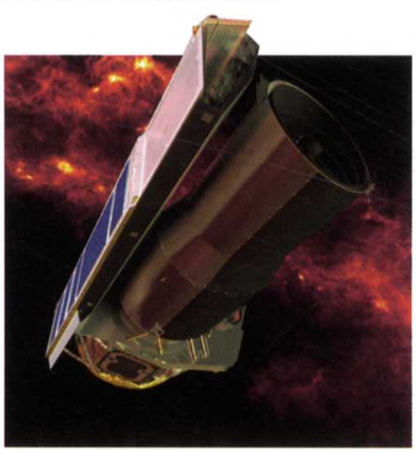
The Chandra X-ray Observatory, third of the Great Observatories, was launched in 1999. Named after Indian-American astrophysicist Subramanyan Chandrasekhar, Chandra studies the Universe at slightly less energetic radiations than CGRO. However, it too faced a problem bringing the radiation to a focus, since X-rays approaching a mirror head-on would pass straight through it.

Chandra uses an ingenious series of curved mirror sections nested one inside the other. X-rays striking the mirrors at a shallow angle ricochet off each in turn, eventually coming to a focus in the X-ray instrumentation. Chandra's cameras produce a much higher resolution than any previously put into orbit, allowing it to produce far better-defined images of X-ray sources.

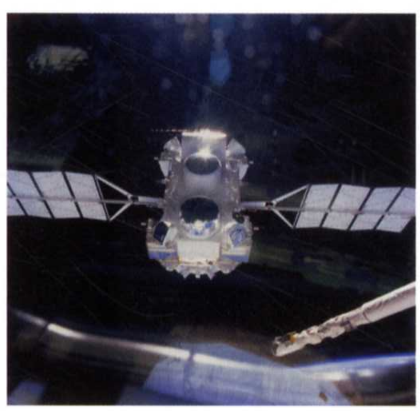
HEAT SEEKER
The Spitzer Space Telescope combines a large telescope with three cryogenically cooled instruments to study infrared radiation. The liquid-helium coolant slowly leaks into space, giving Spitzer a limited life, but it is currently expected to operate for more than five years.



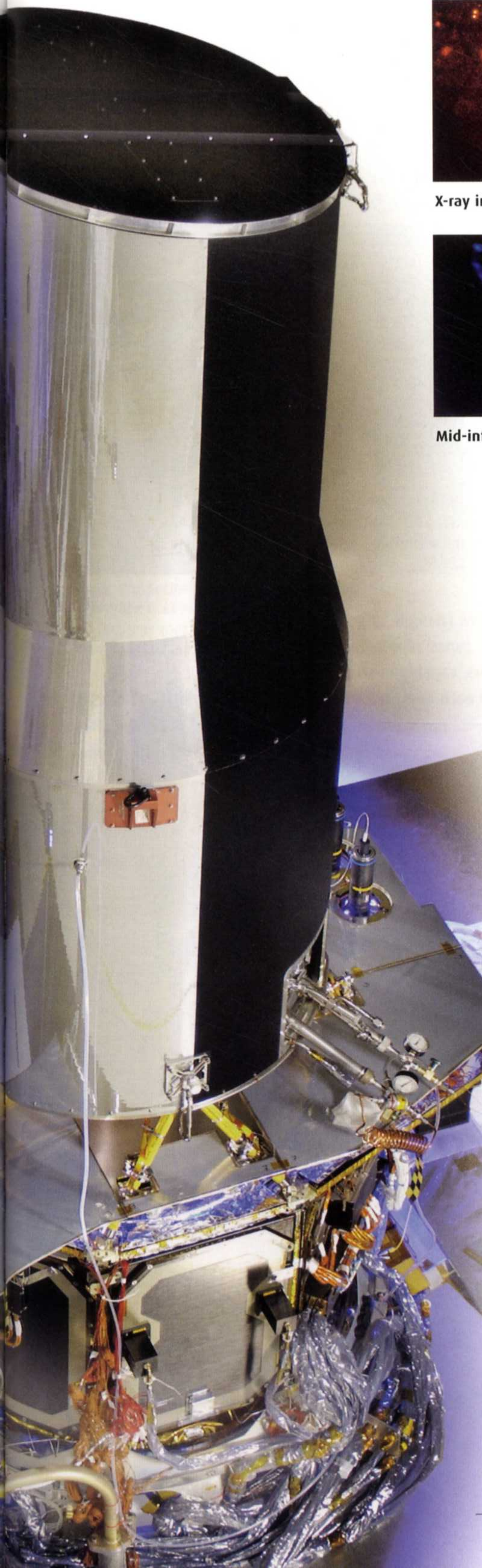
CHANDRA: X-RAYS
The Chandra X-ray Observatory detects high-energy radiation from objects such as supernova remnants and material being pulled into black holes.

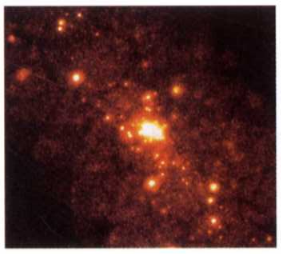


SPITZER: INFRARED
The Spitzer Space Telescope studies infrared radiation, allowing it to peer through opaque gas and dust clouds and to detect relatively cold, dark material in our galaxy and beyond.



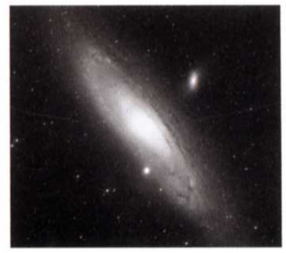
COMPTON: GAMMA RAYS
The CGRO measured radiation from some of the most violent events in the Universe, including supernova explosions and matter-antimatter collisions.





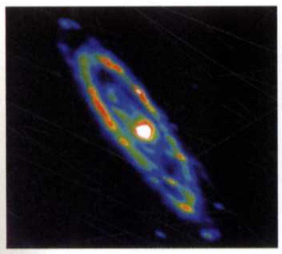
X-ray image

Ultraviolet radiation



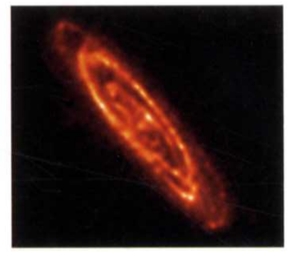
Visible light (filtered)

Visible light

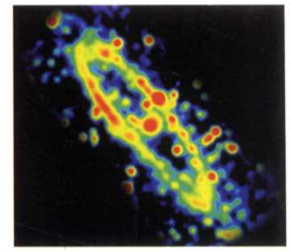


Mid-infrared (IRAS)

Mid-infrared (Spitzer)



Far-infrared



Ground-based radio image

SAME GALAXY, DIFFERENT WAVELENGTHS
The nearest major galaxy to our own, the Andromeda Galaxy (M31), has been studied at every possible wavelength, revealing an array of hidden features – many associated with ring-like dust clouds or the giant black hole at its core.

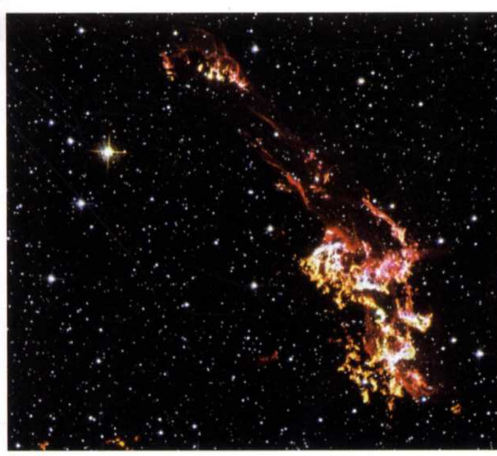
The cold end

The Spitzer Space Telescope, launched in 2003 and named in honour of Lyman Spitzer (see p.252), studies the opposite end of the energy spectrum from Chandra and CGRO – it is the most sophisticated telescope yet built for detecting infrared radiation. The 85cm (34in) telescope mirror focuses light onto three different infrared detectors. Spitzer is designed to peer through galactic dust clouds and look at dim objects such as the faintest stars, as well as planets in the process of formation.

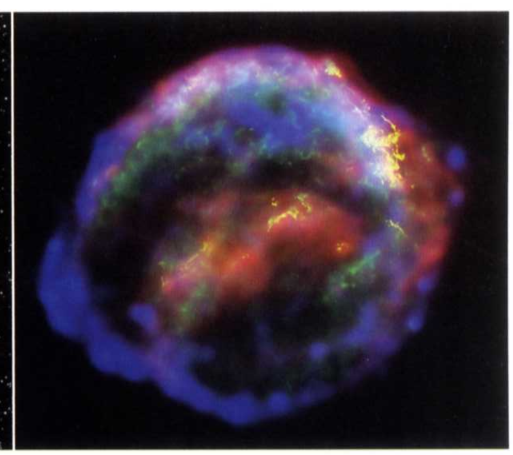
TECHNOLOGY

ORBITING RADIO TELESCOPES

One wavelength not studied by the Great Observatories was radio. Many radio waves reach the ground intact – the challenge is to create detailed images from them. The far longer wavelength of radio compared to light waves calls for much larger telescopes (such as the one shown here), but even the largest radio dish cannot compete with optical resolution. For this reason, signals from distant telescopes are combined in a technique called interferometry. In 1997, Japan launched HALCA, an orbiting receiver that created an interferometer larger than the Earth.



VISIBLE LIGHT
This visible-light image shows the brightest parts of Kepler's Star, the shredded remains of a star that destroyed itself in a supernova explosion in 1604. Only a few glowing filaments are visible.



THE WHOLE STORY
A combined image using invisible radiation from X-rays through to the infrared reveals the true bubble-like structure of Kepler. Only the upper-right portion (shown in the picture on the left) shines in visible light.

Later Moon probes

Through the early 1970s, the Soviet Union compensated for its failure to land men on the Moon with a series of complex unmanned probes. More recent missions have studied our satellite's mineral resources in detail.

12 September 1970
Luna 16, the first robot probe to return samples of Moon rock, launches.

17 November 1970
Luna 17 releases its Lunokhod rover onto the Moon.

28 September 1971
Luna 19, the first in a new wave of Soviet orbiters, is launched.

21 February 1972
The Luna 20 sample-return mission lands in the Apollonius highlands.

19 August 1976
Luna 24's sample-return capsule blasts off from the Sea of Crises.

19 February 1994
Clementine enters orbit around the Moon.

6 January 1998
NASA launches its Lunar Prospector probe.

31 July 1999
Lunar Prospector is crashed into the Moon's south polar region.

27 September 2003
ESA launches its SMART-1 Moon probe.

3 September 2006
SMART-1 crashes into the Moon at the end of its mission.

If it had successfully landed on the Moon in July 1969, Luna 15 might have given Soviet scientists some comfort even as Apollo 11 upstaged their efforts. It was the first in a new generation of Luna probes, equipped with an automatic drill and a small capsule that could bring a sample of lunar dust back to Earth orbit under remote control. Instead, the spacecraft retrorockets failed, sending it slamming into its target zone in the Sea of Crises.

Luna phase II

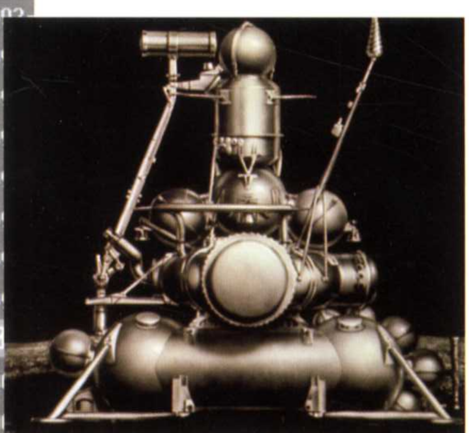
Despite this failure, unmanned craft clearly offered a cost-effective way for Soviet scientists to continue exploring the Moon. Luna 16 worked perfectly, landing on the Sea of Fertility in September 1970 and drilling 100g (3½oz) of rock that was returned to Earth over Soviet territory. Another new type of mission was pioneered by Luna 17 in November 1971. After landing in the Sea of Rains region, the probe released an automatic rover, Lunokhod 1. The size of a small car, it was designed to operate under solar power, with rechargeable batteries to see it through the long lunar night. Lunokhod 1 trundled around the surface for 321 days, photographing its landing area and analyzing the soil chemistry.

The Luna programme continued until 1976, through seven more missions – Luna 21 carried another Lunokhod, while Lunas 18, 20, 23, and 24 were sample-return missions (though 18 and 23 failed for various reasons). Lunas 19 and 22 were advanced orbiting surveyors, capable of changing the shapes of their orbits, and each operated for more than a year.

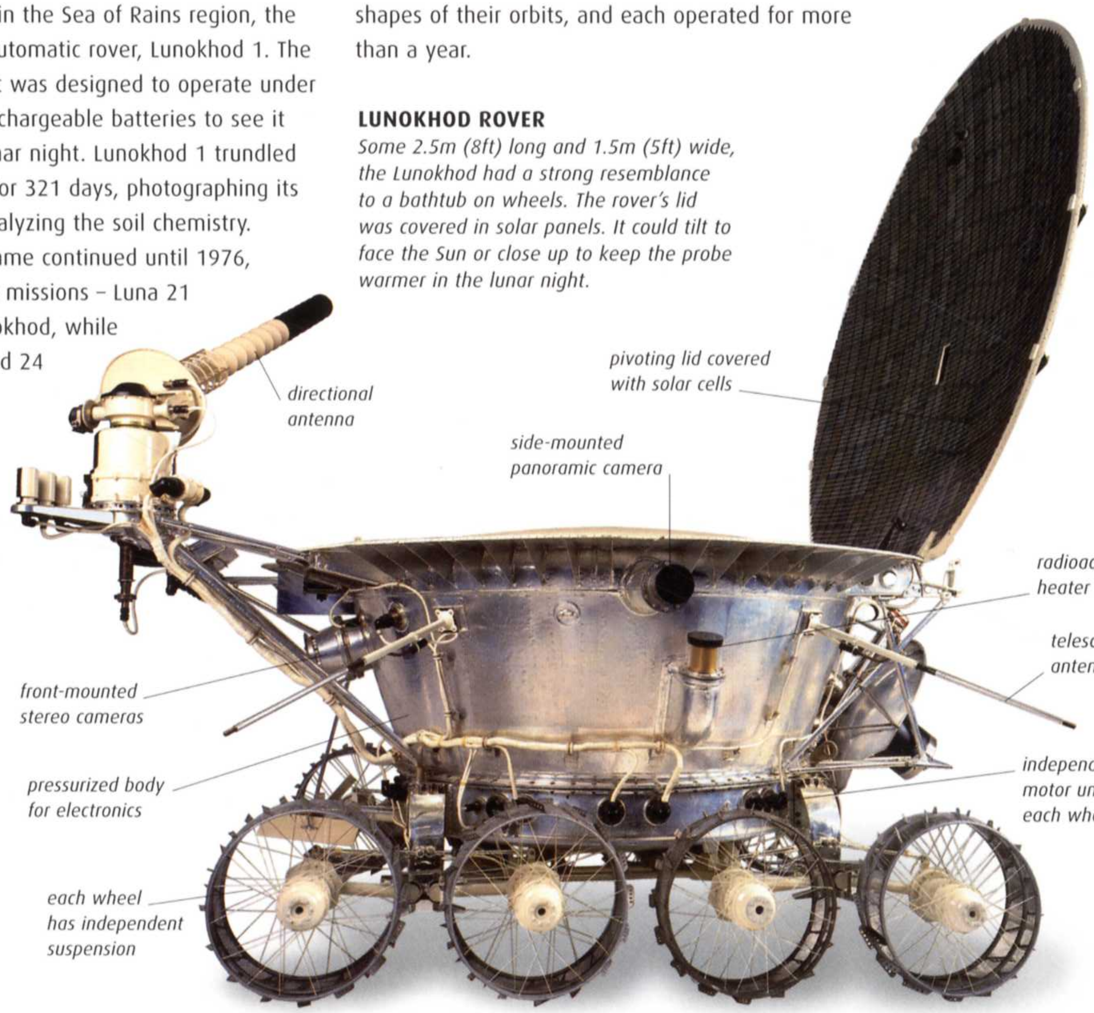
TECHNOLOGY

POLAR SNAPSHOT

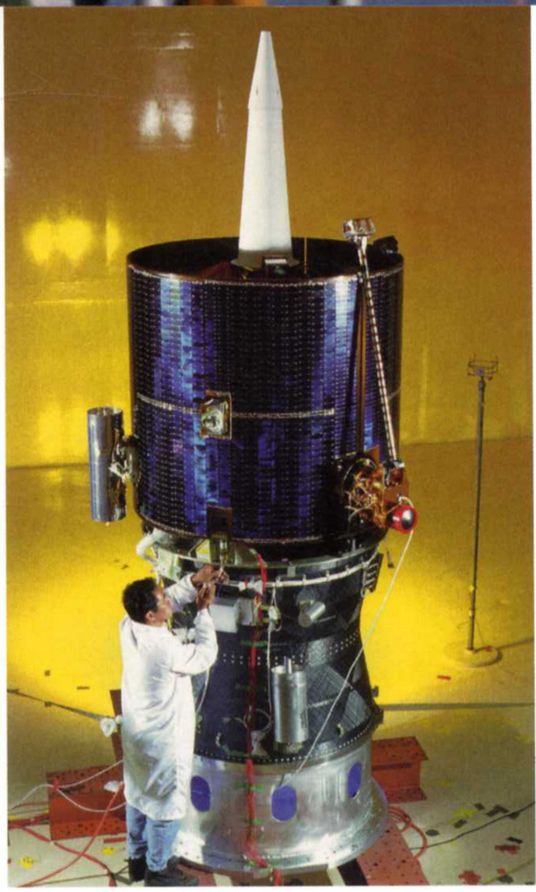
Because the Apollo missions and earlier lunar probes had only moderately inclined orbits, they did not get a good look at the lunar poles. However, their images hinted that there might be a truly enormous depression at the lunar south pole – most likely an ancient impact basin. Clementine confirmed the presence of this vast crater, the South Pole-Aitken Basin, some 2,500km (1,550 miles) across. Because the Sun only ever rises a few degrees into the polar skies, there are deep craters within the basin that never see sunlight, and some of these craters seem to shelter deposits of ice – perhaps deposited by comet impacts.



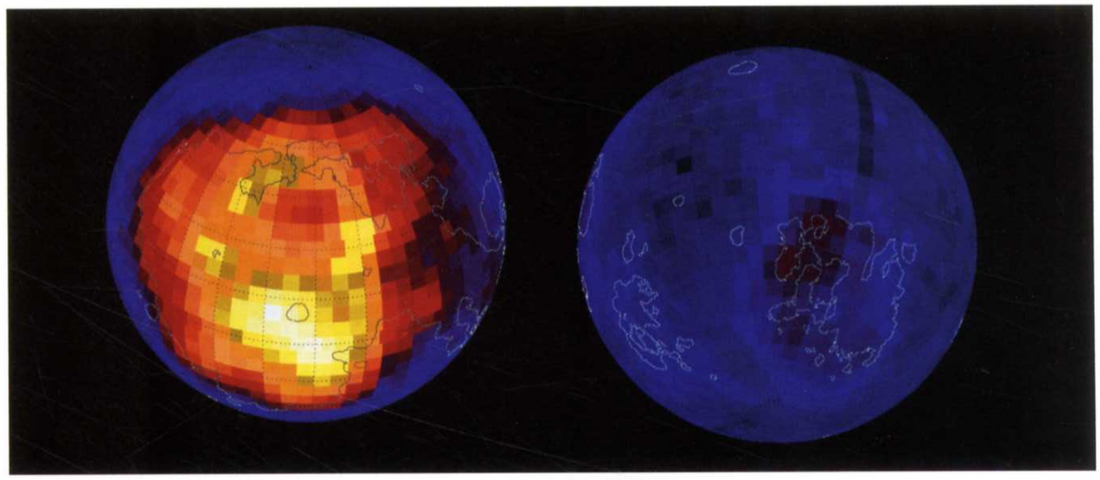
LUNA SAMPLER
Luna 16 and its successors used a two-stage spacecraft. A descent stage fitted with cameras and instruments acted as a launch pad for the cylindrical return capsule.



LUNOKHOD ROVER
Some 2.5m (8ft) long and 1.5m (5ft) wide, the Lunokhod had a strong resemblance to a bathtub on wheels. The rover's lid was covered in solar panels. It could tilt to face the Sun or close up to keep the probe warmer in the lunar night.



LUNAR PROSPECTOR
An engineer makes final adjustments to Lunar Prospector before its launch in 1998. The probe is already mounted on the upper stage that would send it from Earth orbit towards the Moon.



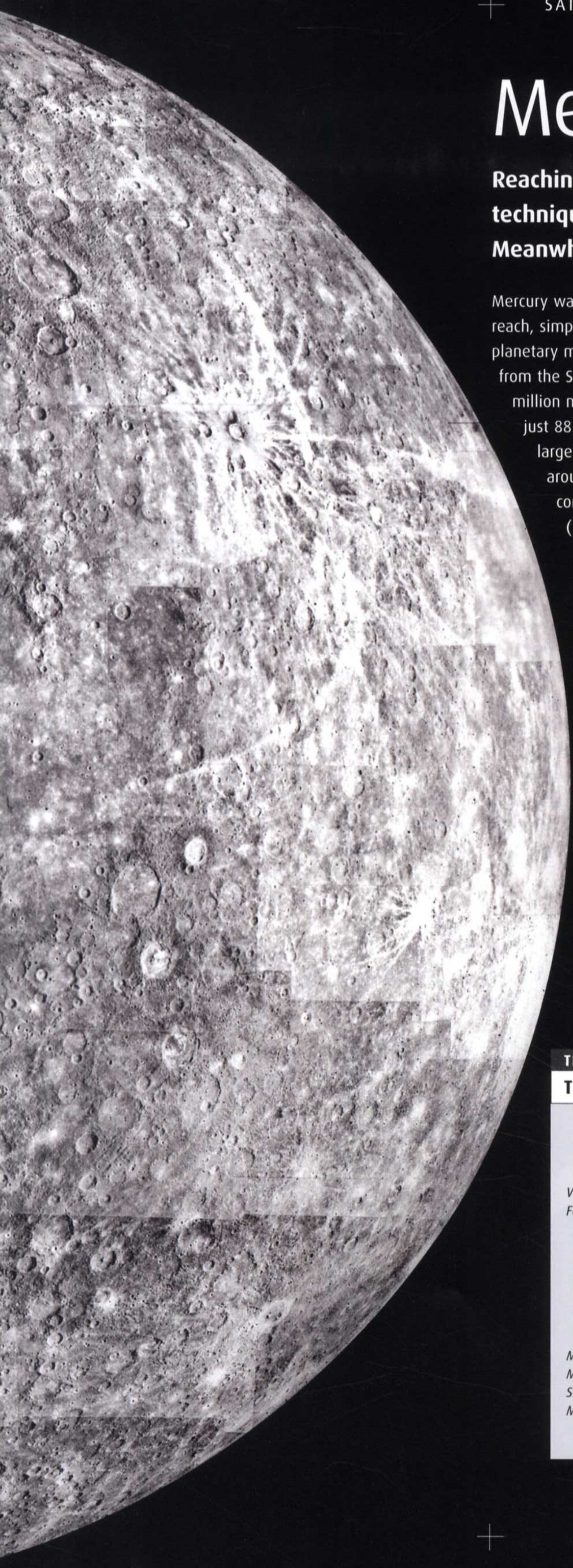
THORIUM ON THE MOON
Lunar Prospector's Gamma Ray Spectrometer allowed it to detect the radioactive signatures of various lunar elements. This map shows the distribution of thorium, a potential nuclear fuel.

Back to the Moon

Following the end of the Luna program, the Moon was ignored for almost two decades. It was only in 1994 that a small spacecraft called Clementine reignited interest in our satellite. A collaboration between NASA and the US Department of Defense (it also tested the endurance of microelectronic components in deep space, beyond the protective Van Allen radiation belts), Clementine was the first probe developed under a "faster, better, cheaper" philosophy introduced at NASA following a series of high-profile, expensive failures. It went from concept to launch in 22 months, and sent 1.8 million digital images of the lunar surface back in just two months of orbital operations. Clementine discovered the first hints of ice at the lunar poles (see panel, opposite) and also photographed lunar terrain at different wavelengths, discovering colour differences that hinted at various minerals in the lunar surface. Building on these discoveries, NASA launched the more ambitious Lunar Prospector probe into orbit in 1998. Prospector was equipped with instruments to study the surface at a wider range of wavelengths. It compiled the first comprehensive mineral maps of the Moon, as well as studying the Moon's gravitational field and its weak magnetism. It reinforced the evidence for ice reserves on the lunar surface, which if proven would make the future colonization of the Moon a great deal easier. NASA hoped that it could clinch the case by sending Lunar Prospector crashing into one of the suspect craters at the end of its mission, but the impact failed to produce the hoped-for spray of icy material.

In 2003, ESA launched a lunar probe of its own, SMART-1. This small spacecraft used an ion drive (see p.282) to travel to the Moon and carried instruments that continued the search for permanently shadowed craters and ice at the lunar poles.

THE VIEW FROM CLEMENTINE
Venus hangs just beyond the Moon in this photograph taken by Clementine above the night side of the Moon. The faint illumination on the right side of the Moon is caused by sunlight reflecting off the Earth.



Mercury and Venus

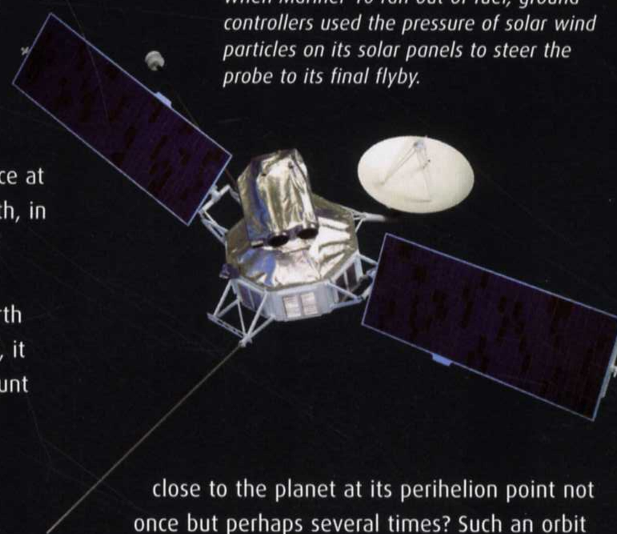
Reaching the innermost planet was a tough challenge for NASA, but techniques used there paved the way for future missions elsewhere. Meanwhile, the Soviet Union finally reached the surface of Venus.

Mercury was always going to be a difficult world to reach, simply because of the immutable laws of planetary motion. With an average distance from the Sun of just 58 million km (36 million miles), Mercury has a year that lasts just 88 Earth days. The tiny planet, little larger than our Moon, moves through space at around 48km (30 miles) per second. Earth, in contrast, moves along its orbit at 30km (19 miles) per second.

For a spacecraft launched from Earth to catch up with Mercury in its orbit, it would have to pick up a huge amount of speed, and when NASA turned its attention towards Mercury in 1968, there was simply no way that even a lightweight probe could achieve such a speed with existing rockets. Fortunately there was an alternative – why not put the Mariner 10 spacecraft into an elliptical orbit around the Sun, designed so that it would orbit once for every two Mercury years, coming close to the planet at its perihelion point not once but perhaps several times? Such an orbit would require far less energy, making the mission possible, but putting Mariner 10 on its elliptical course would mean using an untried theoretical technique – a gravity assist or "slingshot" from Venus (see panel, below). So Mariner 10's mission would not only give scientists a first close-up look at Mercury, it would also act as a rehearsal for later missions using the slingshot technique, such as the TOPS probes (see p.264).

The spacecraft made its first rendezvous with Mercury in March 1974 and sent back images of a cratered, baking world devoid of atmosphere,

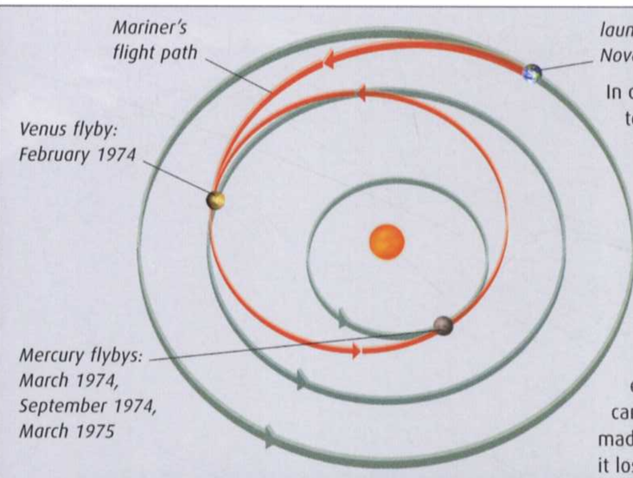
MAPPING MERCURY
This image mosaic was compiled during Mariner 10's final flyby. Because the probe met the planet every two Mercury years, the same areas were illuminated on each flyby.



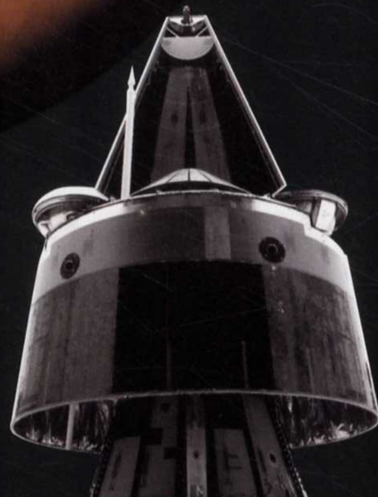
SOLAR SAILOR
When Mariner 10 ran out of fuel, ground controllers used the pressure of solar wind particles on its solar panels to steer the probe to its final flyby.

TECHNOLOGY

THE JOURNEY OF MARINER 10



In order to reach Mercury, Mariner 10 had to enter a precise elliptical orbit with a period of 176 days (two Mercury years), intersecting not just with Mercury's orbit but with the planet itself. It did this by "borrowing" energy from Venus to speed up and change course. As it approached Venus in February 1974, the probe was pulled in by the planet's gravity, accelerating so that it left the encounter on a new elliptical path that carried it closer to the Sun. Mariner 10 made three encounters with Mercury before it lost the ability to manoeuvre.



VENUSIAN ATMOSPHERE
Mariner 10's ultraviolet camera revealed weather patterns in the clouds of Venus for the first time – and in 1979 the Pioneer Venus 1 orbiter took the picture above. The orbiter was combined with a multiprobe mission (right) which deployed probes to study the atmosphere in detail.

TECHNOLOGY

IMAGES FROM THE SURFACE

The thick Venusian atmosphere did such a good job of swamping radio signals from the planet's surface that the later Soviet probes used a different strategy to earlier missions. On Veneras 9 through 14, the landers were carried to the planet by a mothership that remained in orbit while they descended to the surface. The mother ship acted as a signal relay, picking up the data sent from the lander below and re-transmitting it to Earth through clear space. The monochrome and later colour images revealed a Venusian surface scattered with apparently volcanic rocks on a darker layer of "soil" – in fact it now seems that almost all of the surface material originated in volcanic eruptions.

but with many features suggesting that it has had an unusual history. Perhaps the most spectacular discovery was the enormous Caloris Basin, an impact scar some 1,300km (800 miles) across. In September 1974 and March 1975, Mariner 10 made two further flybys of Mercury, successfully photographing some 45 per cent of its total surface. However, the nature of the probe's orbit made it impossible to map the rest of the planet, and Mercury was temporarily abandoned (but see p.306).

Landings on Venus

The Soviet Union's attempts to explore Venus did not begin well – Venera 4, which entered the atmosphere in October 1967, and Veneras 5 and 6 (May 1969) were all lost during their descents. But when the probes were shielded with increasingly heavy armour against the hostile conditions, their luck started to change. Venera 7 was the first probe to make it all the way to the surface – communications failed as it parachuted into the acid skies in December 1970, but when the radio noise that followed was analyzed later, a faint signal was discovered. It showed that the rising atmospheric pressure had levelled off at 90 times that on Earth, while the temperature was a constant 475°C (887°F). The lack of any change revealed that this was the first signal from the surface of another planet.

With confidence in the programme reinforced, 1972's Venera 8 carried an improved radio system. This time, full contact continued all the way to the surface, although the probe stopped working 50 minutes after landing in the harsh environment.

Veneras 9 and 10 had a two-part design, with the lander released by a carrier spacecraft that went into Venusian orbit. These landers were able to send back the first black-and-white images of the planet's surface (see panel, above). Veneras 11 and 12 used a similar technique, delivering information about the atmosphere during their descents and revealing that Venus has lightning. Veneras 13 and 14, which touched down in 1982, sent back higher quality, colour pictures, while the last of the series, Veneras 15 and 16, were orbiters that used radar to map the planet through the clouds. This technique was first used by NASA's Pioneer Venus 1 which orbited the planet for 14 years from 1978. Initially accompanying it was Pioneer Venus 2, which launched a series of four probes to briefly monitor the Venusian atmosphere.

18 October 1967
Venera 4 makes the first Soviet attempt to soft-land on Venus.

15 December 1970
Venera 7 lands successfully on Venus.

3 November 1973
Mariner 10 leaves Earth en route for Mercury.

5 February 1974
Mariner 10 flies past Venus, making the first gravity-assist manoeuvre.

29 March 1974
Mariner 10 makes the first flyby of Mercury.

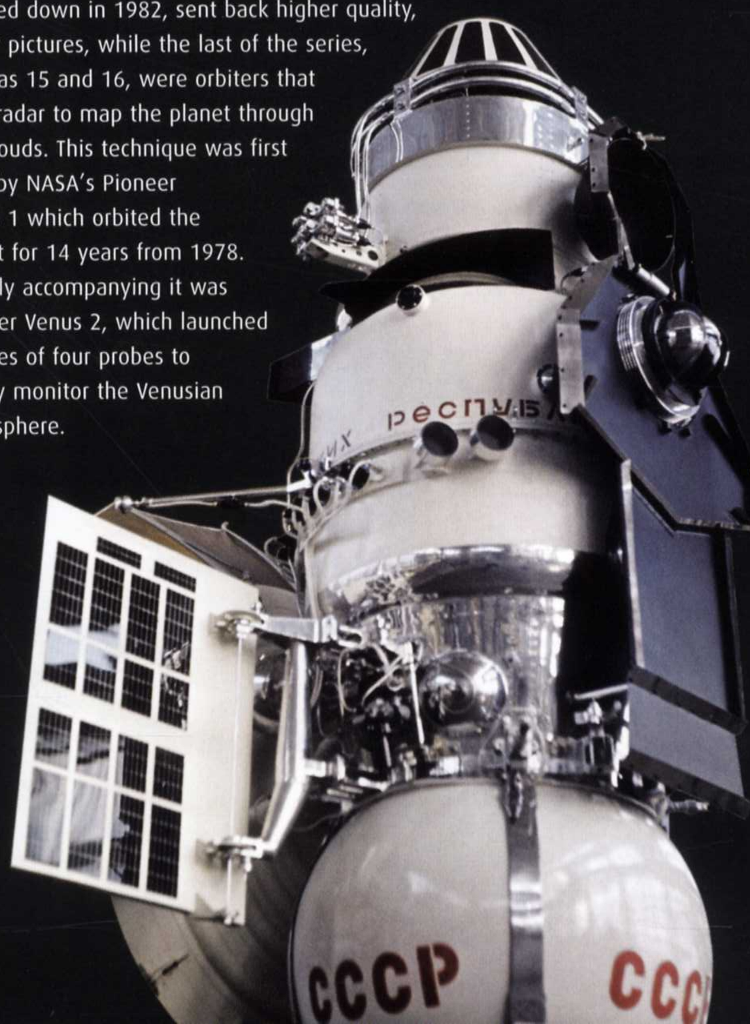
16 March 1975
Stabilized by "sailing" the solar wind, Mariner 10 makes its third and final Mercury rendezvous.

22 October 1975
Venera 9 returns the first pictures from the surface of Venus.

16 November 1978
Pioneer Venus 2 releases the first of its probes into the planet's atmosphere.

4 December 1978
Pioneer Venus 1 arrives in orbit to make the first radar maps of Venus.

10 October 1983
Venera 15 arrives at Venus with a powerful radar mapping system.



RADAR MAPPER
Veneras 15 and 16 carried an early version of the synthetic aperture radar used by Magellan. Once in orbit, the solar panels unfolded and the cone at the top opened to form a radar dish.

9 May 1971
Mariner 8 is launched from Cape Canaveral, but crashes when its launch vehicle fails.

30 May 1971
Mariner 9 is launched successfully toward Mars.

14 November 1971
Mariner 9 enters Martian orbit during a dust storm.

December 1971
The first usable pictures are returned from Mariner 9.

27 October 1972
Mariner 9 is switched off after exhausting the fuel in its attitude control motors.

20 August 1975
Viking 1 launches from Cape Canaveral.

9 September 1975
Viking 2 launches successfully.

19 June 1976
Viking 1 enters orbit around Mars.

20 July 1976
After a hoped-for landing on 4 July to celebrate the US Bicentennial is postponed, the Viking 1 orbiter releases its lander, which parachutes into the atmosphere and lands successfully in the Chryse Planitia region.

7 August 1976
Viking 2 arrives at Mars.

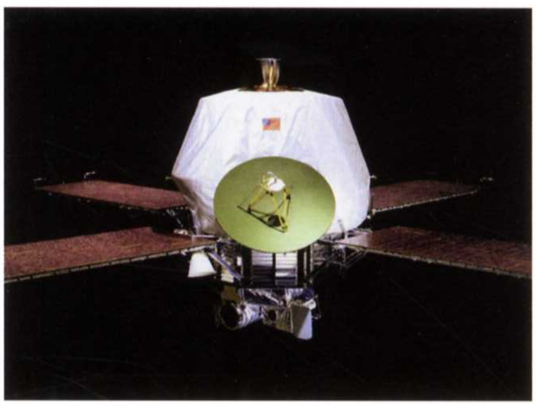
3 September 1976
Viking 2's lander touches down in Utopia Planitia.

Early Mars missions

The first Mariner flybys of Mars had suggested that that the planet was a barren, cratered ball of rock, but throughout the 1970s orbiters and landers revealed a far more complex, fascinating world.

Although Mariners 4, 6, and 7 had all made successful flybys of Mars in the 1960s, no spaceprobe had yet gone into orbit around the planet – but this would change with the Mariner 9 mission. Launched by an Atlas-Centaur rocket, this probe (with its failed twin, Mariner 8) was the first to be equipped with a retrorocket that would allow it to lose excess speed and drop into orbit around Mars. When it arrived after a six-month journey in November 1971, the Red Planet was enveloped in one of its periodic global dust storms, but as the atmosphere began to clear over the following weeks, an unexpected landscape emerged. The northern hemisphere was dominated by huge volcanoes towering above smooth lowland plains. These included a peak which was later named Olympus Mons – the largest volcano in the Solar System, some 500km (300 miles) across and rising to 27km (17 miles) above the average Martian surface. Perhaps even more impressive was the deep canyon system called the Valles Marineris (Mariner Valleys). These huge scars in the Martian surface dwarf Earth's own Grand Canyon. They stretch for more than 4,000km (2,500 miles) around the Martian equator and are more than 10km (6 miles) deep and 600km (375 miles) across in places. Unlike their Earthly equivalent, it was clear that these valleys were produced by faults in the Martian crust, not a result of water erosion – but elsewhere, Mariner 9 photographed winding valleys, "islands", and outflow channels that looked very much like the result of water flowing in the planet's ancient past.

How had the three previous probes so misled the scientists? By a fluke of their flightpaths, each had photographed only the rocky, cratered highlands dominating the southern hemisphere – Mars is a world of two halves, and until 1971 its interesting side had been missed.

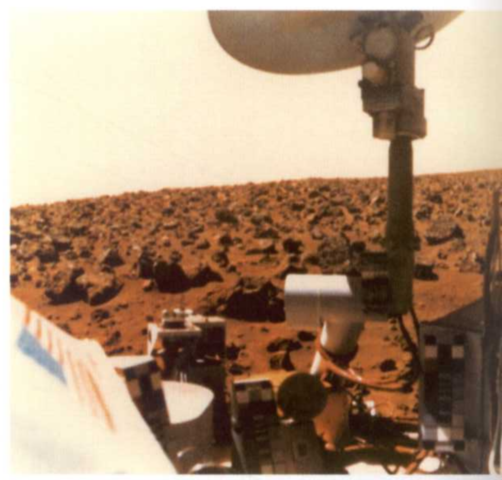


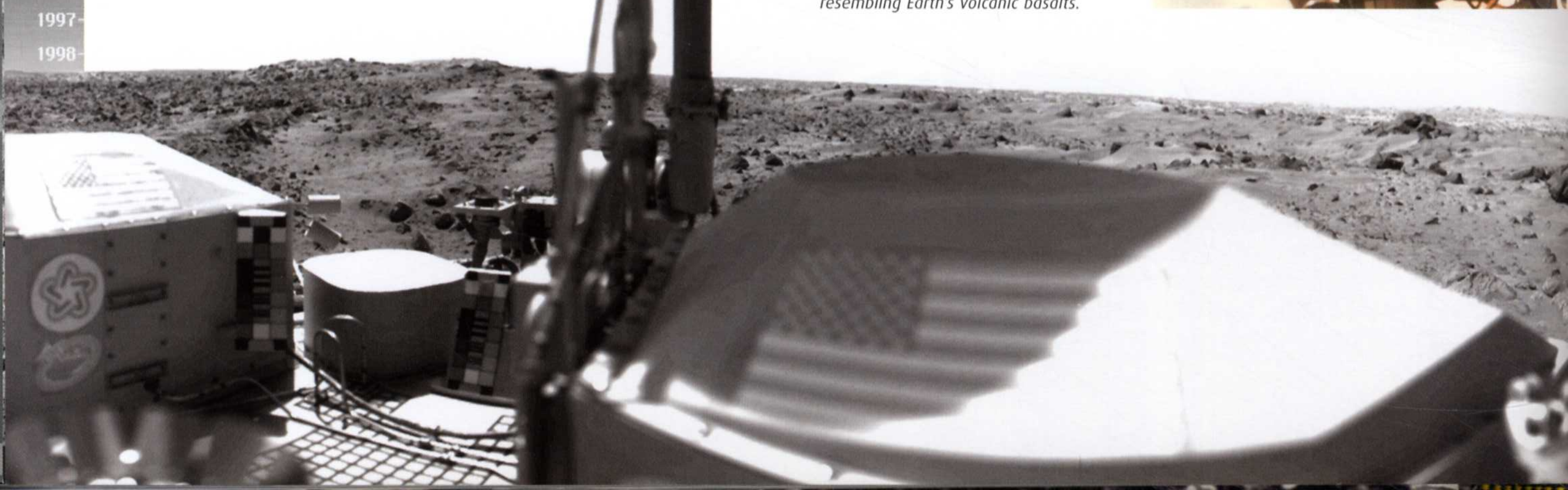
FIRST ORBITER
Mariner 9 was different from earlier Mariner probes in several respects – it had larger solar arrays to generate power and a retrorocket to slow it down as it reached Mars.

Outposts on Mars

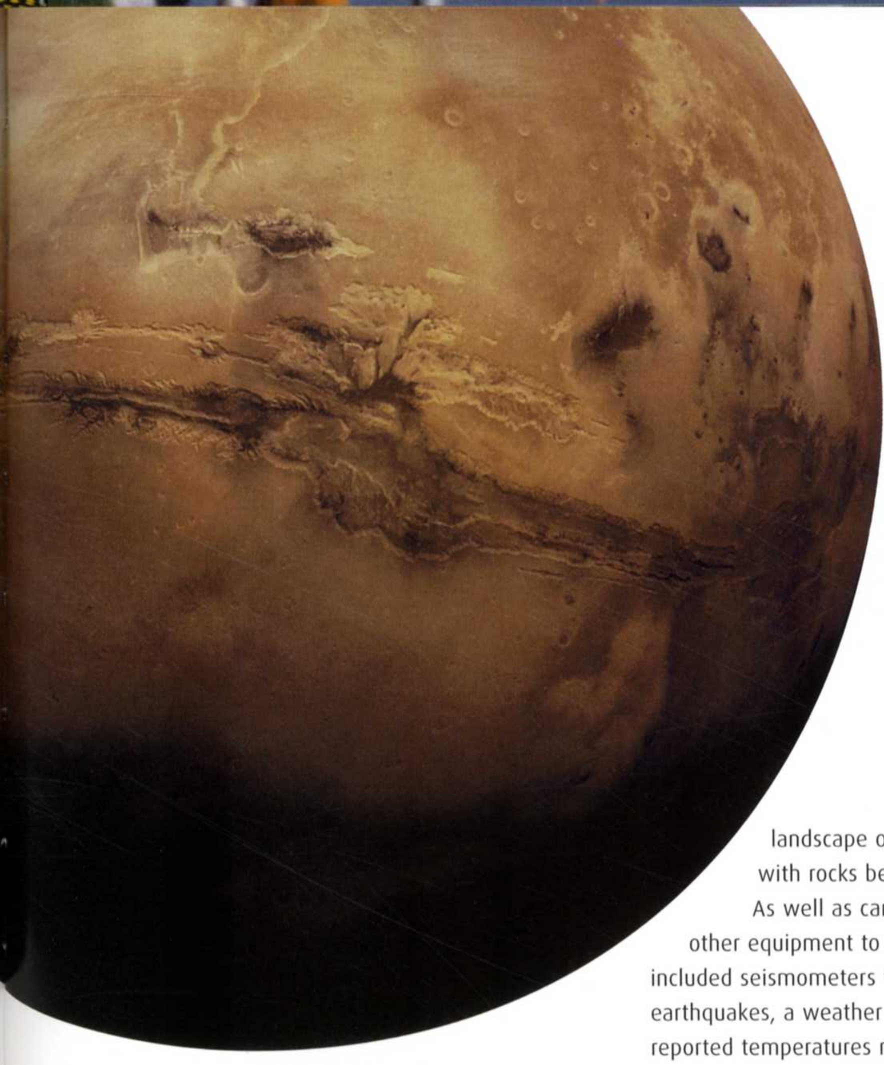
In 349 days of operation, Mariner 9 transformed the scientists' image of Mars – now it seemed that the

VIKING'S VIEW
The Viking orbiters compiled a comprehensive photographic atlas of Mars, allowing the production of mosaics of entire hemispheres. This view is dominated by the Valles Marineris canyon system and huge volcanoes on the left-hand limb.





VIEWS FROM THE GROUND
The Viking landers found variations in the terrain around the planet. Viking Lander 1's location (below) had fewer rocks and more windblown sand dunes. Viking Lander 2's landing site (right) was strewn with many more rocks, resembling Earth's volcanic basalts.



TECHNOLOGY

THE VIKING ORBITERS AND LANDERS

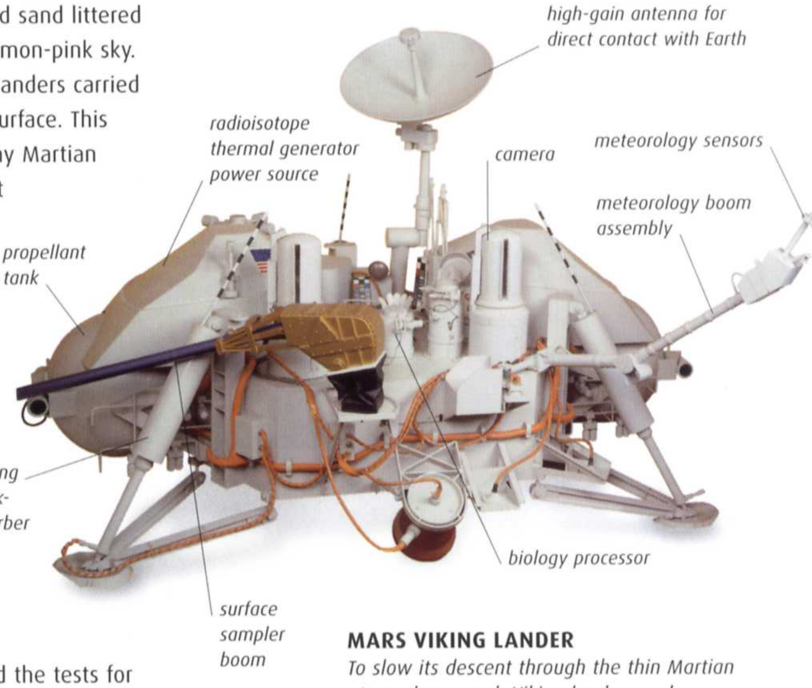
The Viking orbiters were based on the successful Mariner template but considerably enlarged. Cameras and other instruments were mounted on a movable platform attached to an octagonal body 2.4m (100in) across. The body held most of the probe's electronics, while an antenna beamed data from the orbiter and lander back to Earth. On the back of this octagon was a rocket motor that slowed the probe down as it arrived at Mars, while the lander itself, sealed inside a sterile outer shell, was attached to the front. The landers were thoroughly sterilized before launch to prevent contamination of the Martian surface or the biology experiments with organic material or bacteria from Earth. Once at Mars, Viking's operators used images from the orbiter to study potential landing sites before releasing the lander.

possibilities of water and even life at some point in Martian history were back on the agenda. The advanced Viking missions, in development since 1969 and now scheduled for launch in 1975, suddenly became a focus of intense interest.

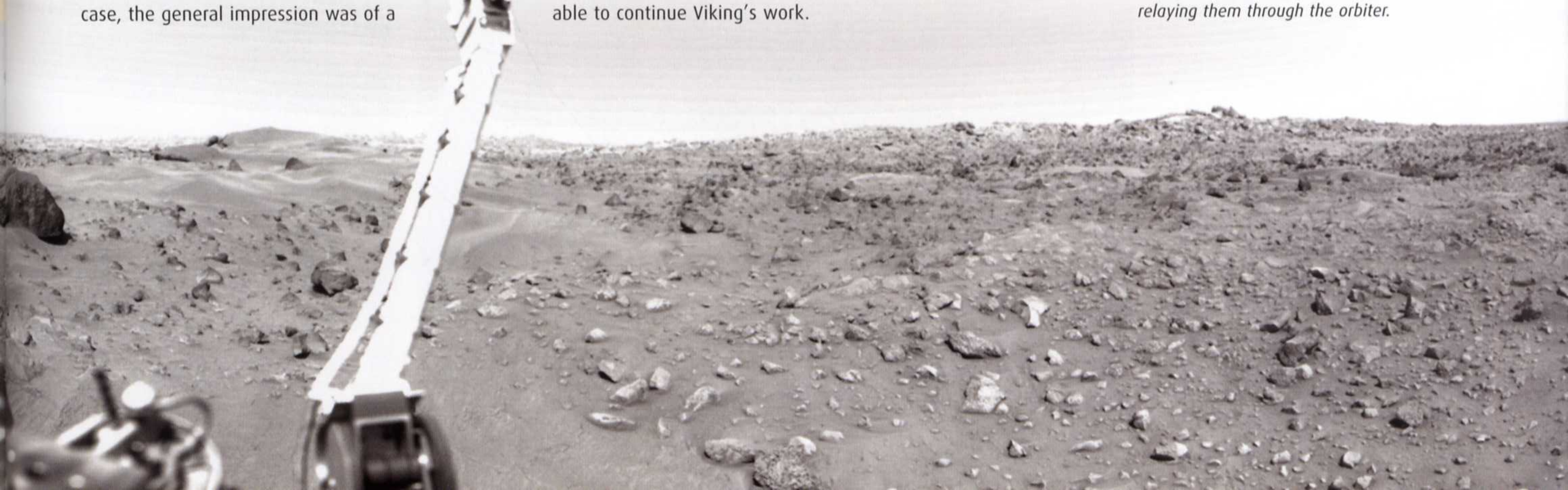
Twin Viking spacecraft were planned, each with two elements – an orbiter and a lander (see panel, above). Viking 1 arrived in orbit around Mars in June 1976, while Viking 2 arrived in August. The orbiters continued to photograph the entire planet at relatively high resolutions until 1980, but attention soon switched to the landers, which parachuted to the ground in July and September. The pictures they sent back recorded the landscapes of the Chryse Planitia and Utopia Planitia regions respectively, and in each case, the general impression was of a landscape of orange-red sand littered with rocks beneath a salmon-pink sky.

As well as cameras, the landers carried other equipment to study the surface. This included seismometers to detect any Martian earthquakes, a weather station that reported temperatures ranging from -120°C (-184°F) at night to -14°C (7°F) in the day, and a sampler arm to scoop up and study Martian soil.

Most attention, however, focused on the biology processor – a set of three experiments that looked for evidence of photosynthesis, bacteria, or just organic (carbon-based) matter in the soil samples. While there was no sign of photosynthesis at work, and the tests for organic matter also drew a blank, the soil did appear to react when "fed" with nutrients. Most scientists thought this was due to unusual chemistry rather than life, but the results were inconclusive. However, it would be a long time before another probe was able to continue Viking's work.



MARS VIKING LANDER
To slow its descent through the thin Martian atmosphere, each Viking lander used parachutes at first and then retrorockets. The lander's sterile shell also shielded it during atmospheric entry, before falling away during the final approach. Onboard antennae allowed for communications with Earth, either sending signals directly or relaying them through the orbiter.



1972

2 March 1972
Pioneer 10 is launched on its 20-month long journey to Jupiter.

5 April 1973
Pioneer 11 sets out on its journey to Saturn via Jupiter.

3 December 1973
Pioneer 10 makes the first flyby of Jupiter.

5 March 1979
Voyager 1 makes its flyby of Jupiter. Voyager 2 follows four months later.

1 September 1979
Pioneer 11 makes the first flyby of Saturn.

12 November 1980
Voyager 1 flies through the Saturn system and makes a close approach to Titan.

25 August 1981
Voyager 2 flies past Saturn and heads on to Uranus and Neptune.

24 January 1986
Voyager 2 makes the first flyby of Uranus.

25 August 1989
Voyager 2 makes the first flyby of Neptune.

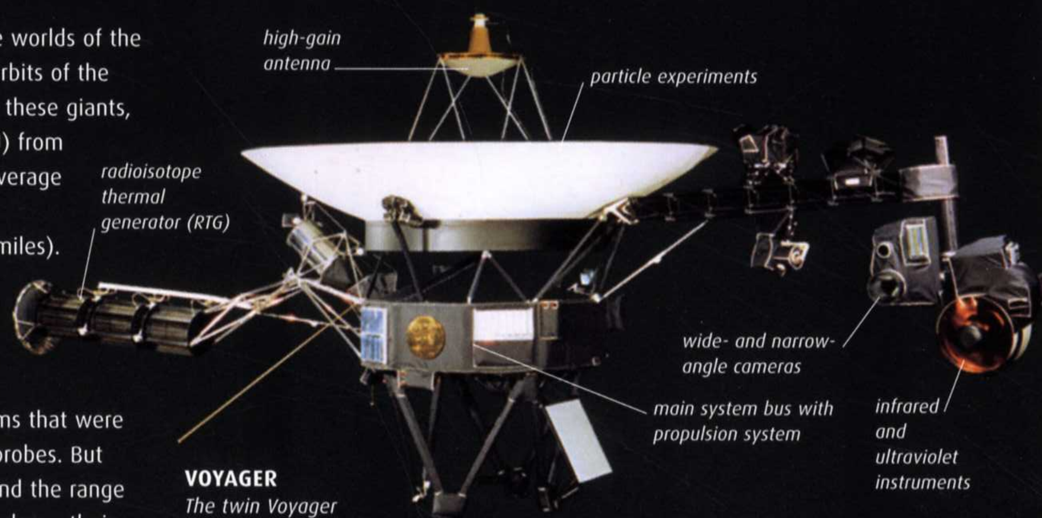
Voyages among giants

The successful use of a gravity assist by Mariner 10 opened the way for ambitious missions to cross the vast distances between the giant outer planets of the Solar System.

The space in which the inner, Earthlike worlds of the Solar System orbit is dwarfed by the orbits of the four outer planets. Even the closest of these giants, Jupiter, orbits 5 astronomical units (AU) from the Sun (an astronomical unit is the average distance between Earth and the Sun, roughly 150 million km or 93 million miles). The outermost giant, Neptune, is some 30 AU away from the Sun.

The giants are huge balls of gas surrounded by large families of moons and moonlets – complex systems that were an obvious scientific target for space probes. But their great distance placed them beyond the range of easy targets for Space Race spectaculars – their exploration would be a long-term endeavour.

NASA launched two initial probes, Pioneers 10 and 11, towards Jupiter and Saturn in 1972 and 1973 respectively. These became the first objects to cross the asteroid belt between Mars and Jupiter, proving that it was largely empty space and the risk of a collision was small. Pioneer 10 reached its target in December 1973, and sent back pictures that improved on Earthbound telescopes, but still left many questions unanswered. Pioneer 11 swung past Jupiter in 1974 and used the giant planet's gravity to swing it towards Saturn, which it reached in 1979. By this time, a more sophisticated pair of probes was already following in its wake.



VOYAGER
The twin Voyager probes bear a distinct resemblance to their Mariner ancestors. Stabilized by small thrusters, they orient themselves in space by tracking the Sun and the bright star Canopus.

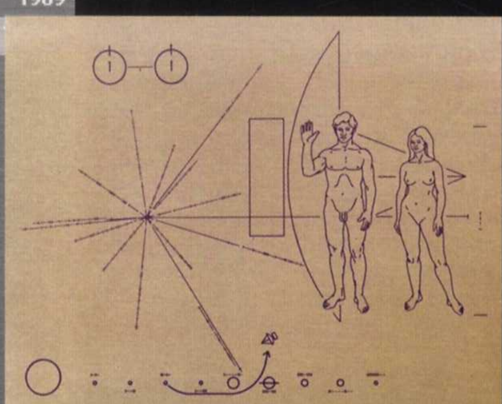
Planning the Voyagers

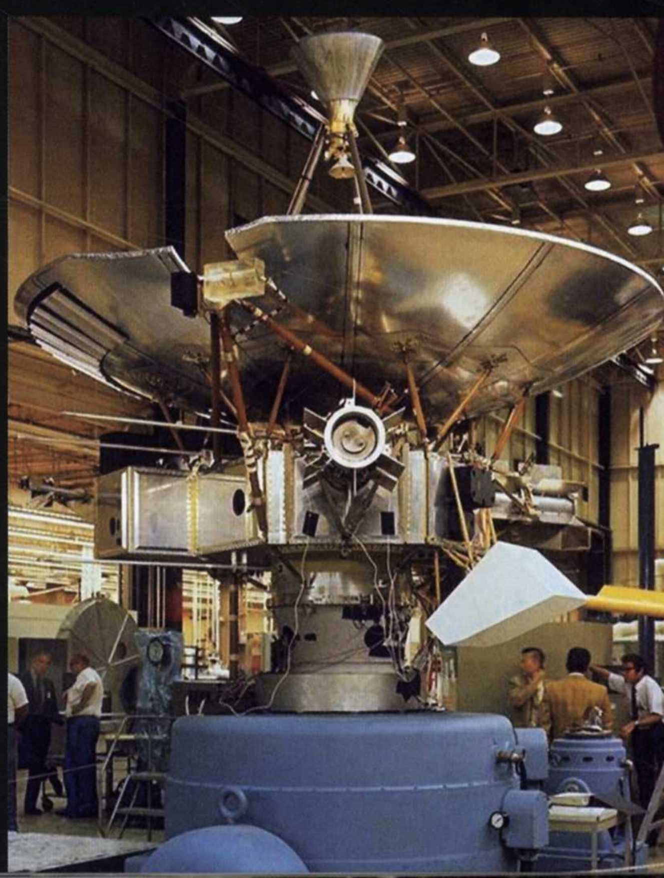
During their initial studies of gravity assist in the 1960s, scientists had noticed that the giant planets would fall into a particularly neat arrangement in the late 1970s. A spacecraft launched during this alignment, which only occurs once every 176 years, would be able to make a "grand tour" of the outer Solar System, receiving from each giant planet in turn a gravity boost that would alter its course and accelerate it towards its next target. The opportunity was too good to miss, and NASA began to develop plans for a Thermoelectric Outer Planets Spacecraft (TOPS). However, as the mission grew more ambitious and complex, its budget spiralled, leading to its cancellation amid the cutbacks of 1972.

With just a few years until the launch window, NASA went back to the drawing board, designing a simpler probe based on Mariner technology. By the time the mission was ready in 1977, the twin spacecraft had developed so far from Mariner that they were given a new name – Voyagers.

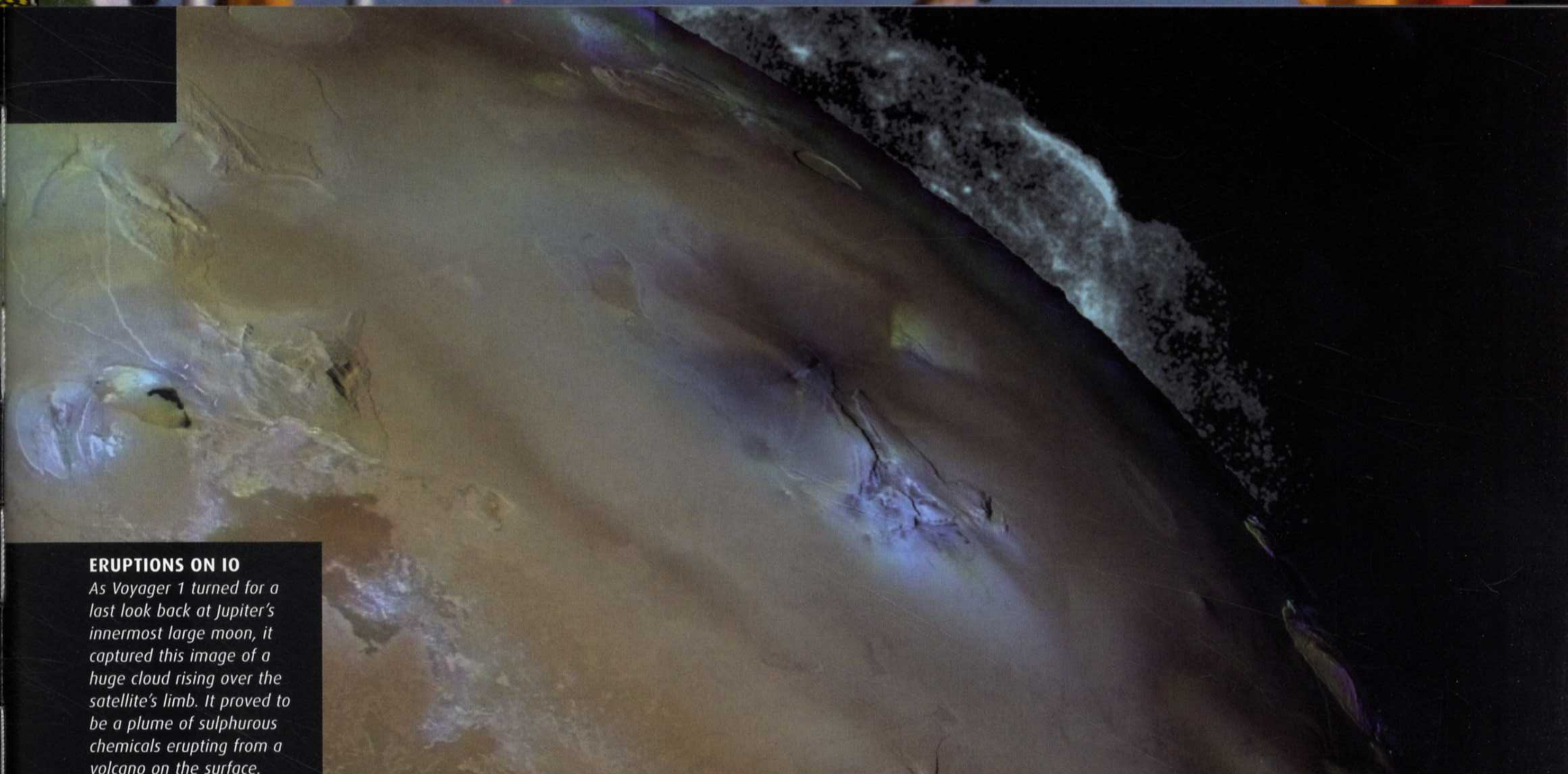
Grand tourists

The Voyager mission design called for Voyager 1 to travel on a faster trajectory than its sibling, and so Voyager 2 was launched first, on 20 August 1977, and Voyager 1 took off 15 days later. Voyager 1





PIONEER AND ITS PLAQUE
The Pioneer probes (right) to Jupiter and Saturn were to be the first human objects sent to go beyond the Solar System, and the mission scientists felt it was important to send a greeting to any alien civilisation that might one day find them. To this end, they devised a plaque (above) that shows a man and a woman, along with basic directions to reach Earth.

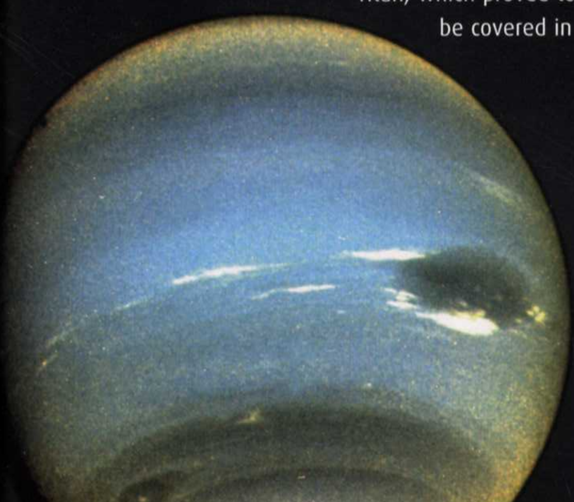


ERUPTIONS ON IO
As Voyager 1 turned for a last look back at Jupiter's innermost large moon, it captured this image of a huge cloud rising over the satellite's limb. It proved to be a plume of sulphurous chemicals erupting from a volcano on the surface.

swung past Jupiter on 5 March 1979, followed in July by its twin. The probes sent back the first close-up images of the large moons Io, Europa, Ganymede, and Callisto. These revealed active sulphur volcanoes on Io, an icy crust with hints of a hidden ocean on Europa, and a thin ring of dust around Jupiter itself.

At Saturn, the paths of the Voyagers diverged. Voyager 1 swung close to the planet, photographing its famous rings and flying past the giant moon Titan, which proved to be covered in a smoggy orange atmosphere. Voyager 2 flew past further out, using gravity assist to sling it on towards an encounter with Uranus in 1986. Here it found an eerily placid green world and an array of moons, including the bizarre Miranda with a surface that seems to be a jumble of different terrain types.

The final leg of the probe's marathon journey carried it on to Neptune in 1989. This proved to be a far more active world, with dark storms and high winds raging in its blue atmosphere. Its large satellite, Triton, was even stranger – with geysers of liquid nitrogen and a surface temperature of -238°C (-396°F). Leaving Neptune behind in its wake, Voyager 2 headed into the outer limits of the Solar System – like Voyager 1 and its Pioneer siblings, it is moving fast enough to leave the Solar System forever and wander among the stars.

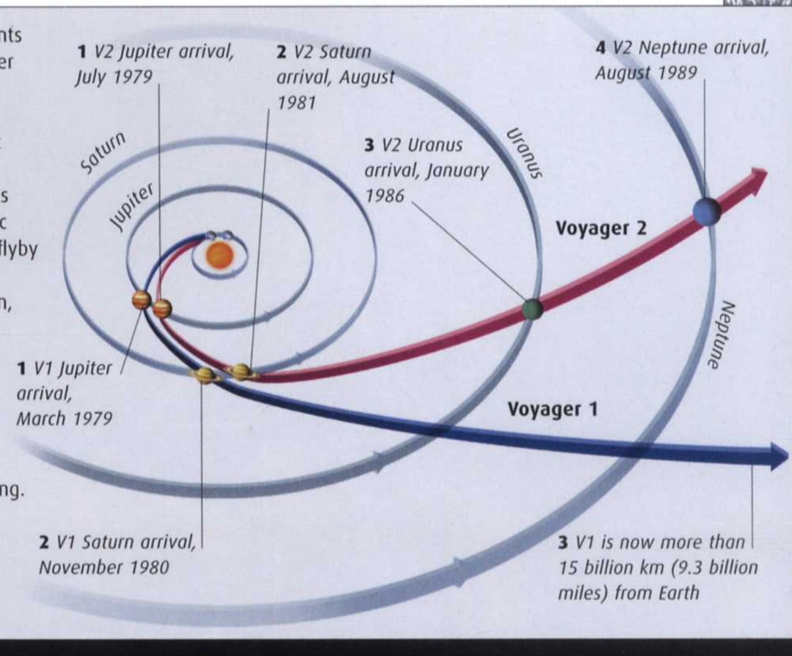


STORMS ON NEPTUNE
So far out in the Solar System, Neptune was expected to be a placid, deep-frozen world. Instead, Voyager 2 found huge storm systems and some of the highest wind speeds in the Solar System – all powered by an unknown internal energy source.

TECHNOLOGY

SLINGSHOTS ACROSS THE SOLAR SYSTEM

Gravity assist put strict constraints on the flightpaths of the Voyager probes. The main goals of the mission were to revisit Jupiter and Saturn and get a good look at Jupiter's four large satellites and Saturn's moon Titan. Uranus and Neptune were an optimistic afterthought, but a close Titan flyby would make it impossible for a probe to continue towards them, so mission designers came up with a contingency plan. Voyager 1 took a fast route to Saturn and Titan, while Voyager 2 followed a slower path that could be diverted to Titan if something went wrong. Fortunately nothing did, and the extension of Voyager 2's mission was authorized shortly after its Saturn encounter.



4 May 1989
NASA's Magellan probe is deployed from the Space Shuttle *Atlantis*. Because of scheduling difficulties that arose in the aftermath of the *Challenger* disaster, Magellan has to follow a long route to Venus, taking 15 months.

10 August 1990
Magellan arrives at Venus and enters a near-polar orbit, circling the planet every 3 hours 15 minutes.

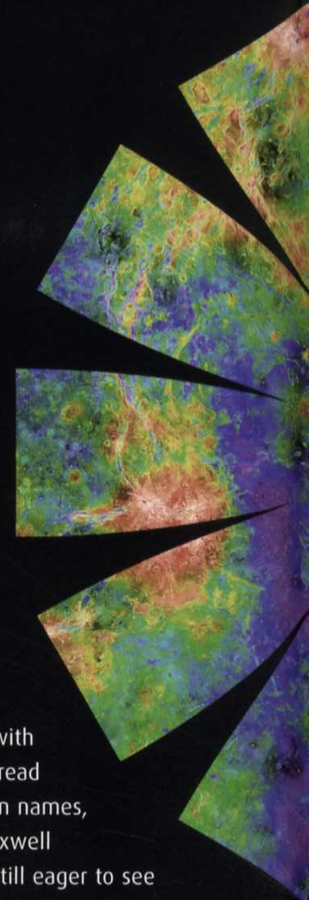
15 May 1991
The probe completes its primary 243-day mission, mapping more than 80 per cent of the Venusian surface, and then enters an extended phase of operations.

14 September 1992
With three mapping cycles complete, Magellan begins a new phase of its mission, in which variations in its orbit are used to map Venusian gravity.

May 1993
Magellan lowers its orbit using the new technique of aerobraking.

11 October 1994
Magellan is deliberately plunged into the atmosphere of Venus at the end of its successful five-year mission.

Mapping Venus



The task of charting what lay beneath the choking Venusian atmosphere required an ingenious application of Earth-based remote-sensing techniques to the problems of a more distant world.

While the Soviet Union had little luck further afield in the Solar System, their probes dominated the exploration of Venus in the 1970s and 1980s. The only US effort of the period was the Pioneer Venus mission of 1978 (see p.261). However, this did introduce a new technique to solve the problem of Venus's perpetual cloud cover. Radar had first been used to study Venus from Earth in 1961, but Pioneer brought a radar instrument to Venus itself for the first time.

The idea behind radar altimetry is simple – radio waves are fired from a spacecraft at the ground below, and a receiver on the spacecraft picks up their reflected echoes. Because the radio waves travel at a known speed (the speed of light), it is easy to calculate the distance of the ground from the time the signal takes to return. In Earthbound applications, the principle is used to calculate the distance of a spacecraft from tracking stations at known locations, but the method can be reversed – if the craft's orbit is known precisely, then the reflection time can reveal the height of the terrain below – mountain peaks will return echoes sooner than deep chasms, for example.

VENUS UNVEILED
A spherical projection of Magellan data, with colours inspired by the Venera surface images, shows what Venus might look like with its clouds stripped away.

The Pioneer studies were followed by two Soviet orbiters, Veneras 15 and 16. A vague picture was emerging of a low, flat planet, with a few high plateaus and widespread volcanic peaks. These were given names, such as Alpha Regio and the Maxwell Montes, but astronomers were still eager to see more detail of the Venusian landscape, and that would require another, more sophisticated probe.

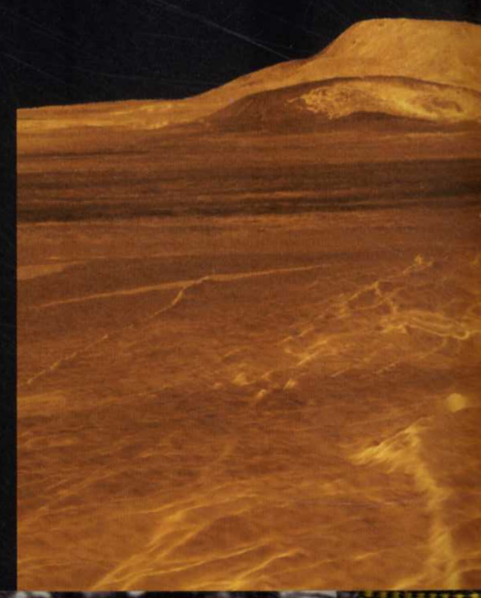
The Magellan mission

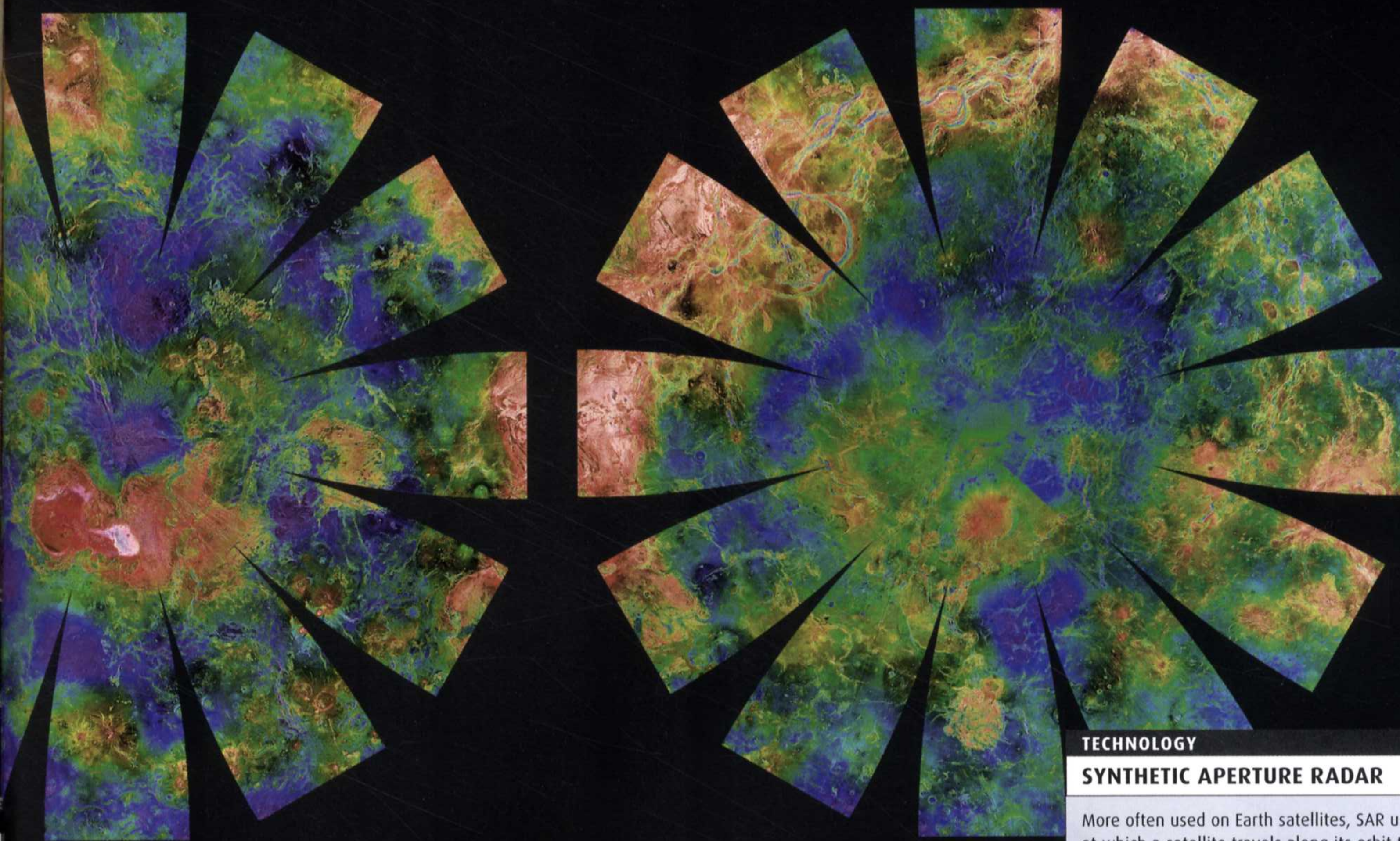
NASA's original successor to Pioneer Venus was VOIR (Venus Orbiting Imaging Radar). This would have been a huge spacecraft fitted with six different instruments. When costs and complexities began to spiral, the project was cancelled, to be replaced by a stripped-down Venus Radar Mapper (VRM) mission. In 1986, VRM was renamed Magellan, in honour of the famous Portuguese explorer.

Magellan carried an ingenious synthetic aperture radar (SAR), using the same principle as normal radar but producing maps with far higher resolution (see panel, opposite). New techniques allowed the science team on Earth to extract even more information from the radar data – as well as basic topography, they could measure the

MAGELLAN SPACECRAFT
The main 3.5m (11½ft) dish on the Magellan orbiter (shown here under construction at the Martin Marietta factory in Denver) played dual roles. During half of its orbit around Venus, it received SAR signals transmitted by the cone-like horn antenna (on the left of the dish). For the other half of its orbit, the probe turned to face Earth and the dish beamed back the data it had gathered.

RARE IMPACT
Magellan showed that impact craters are rare on Venus. The thick atmosphere means that most incoming objects burn up before impact, so craters like Dickinson, 69km (43 miles) across, are amongst the smallest to form.





steepness and roughness of the terrain and even identify different rock types based on the strength with which they reflected Magellan's radar.

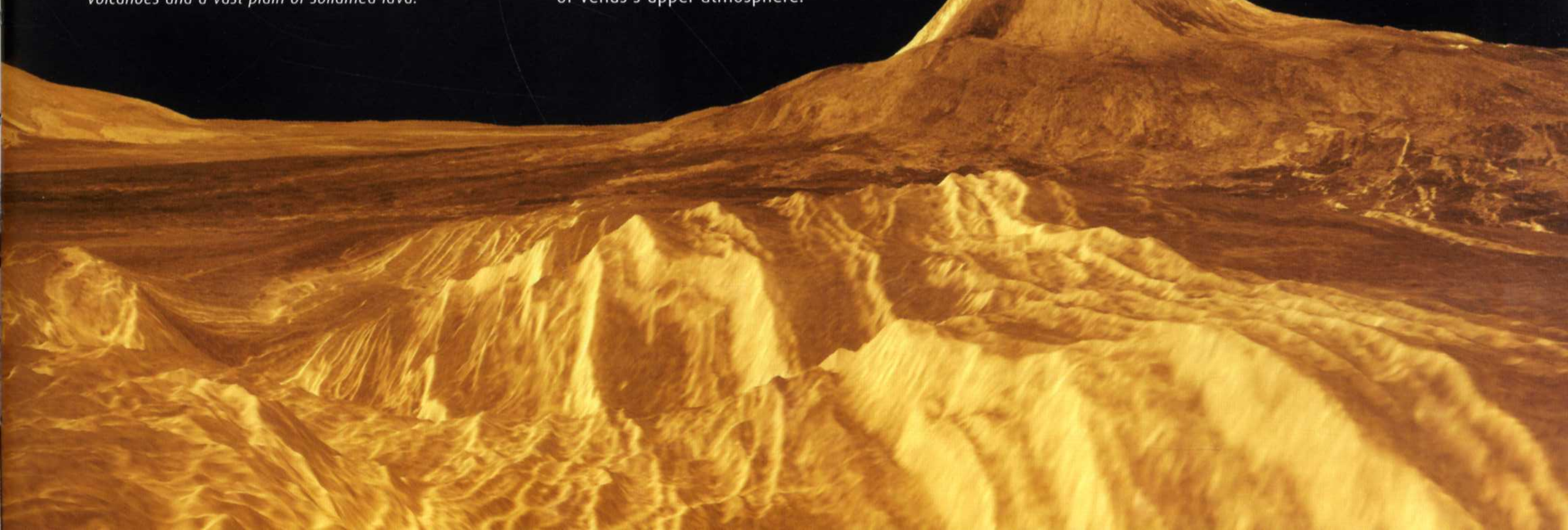
In order to map as much of Venus as possible, Magellan entered an orbit that took it over the planet's poles. Each orbit generated a narrow strip of radar data wrapping around the planet, and, as Venus slowly rotated beneath the probe, a picture of the entire surface built up. By the end of three Venusian rotations (each 243 Earth days long), the probe had mapped 98 per cent of the surface of Venus at a resolution of around 100m (330ft). With Magellan far outlasting its expected life, the next three 243-day mapping cycles were used to build up a model of variations in the planet's surface gravity. During this phase of the mission, the probe's orbit was gradually lowered until it skimmed the upper atmosphere and lost a little of its speed each time – a rehearsal for a fuel-saving technique called aerobraking (see p.274). As a finale, Magellan made a dramatic death plunge towards the surface, its radio signals revealing the properties of Venus's upper atmosphere.

MAPPING VENUS
Magellan data was used to produce detailed global maps of Venus, such as these of the northern (left) and southern hemispheres. Highland areas are shown in cream and white, lowlands in blue and purple.

TECHNOLOGY

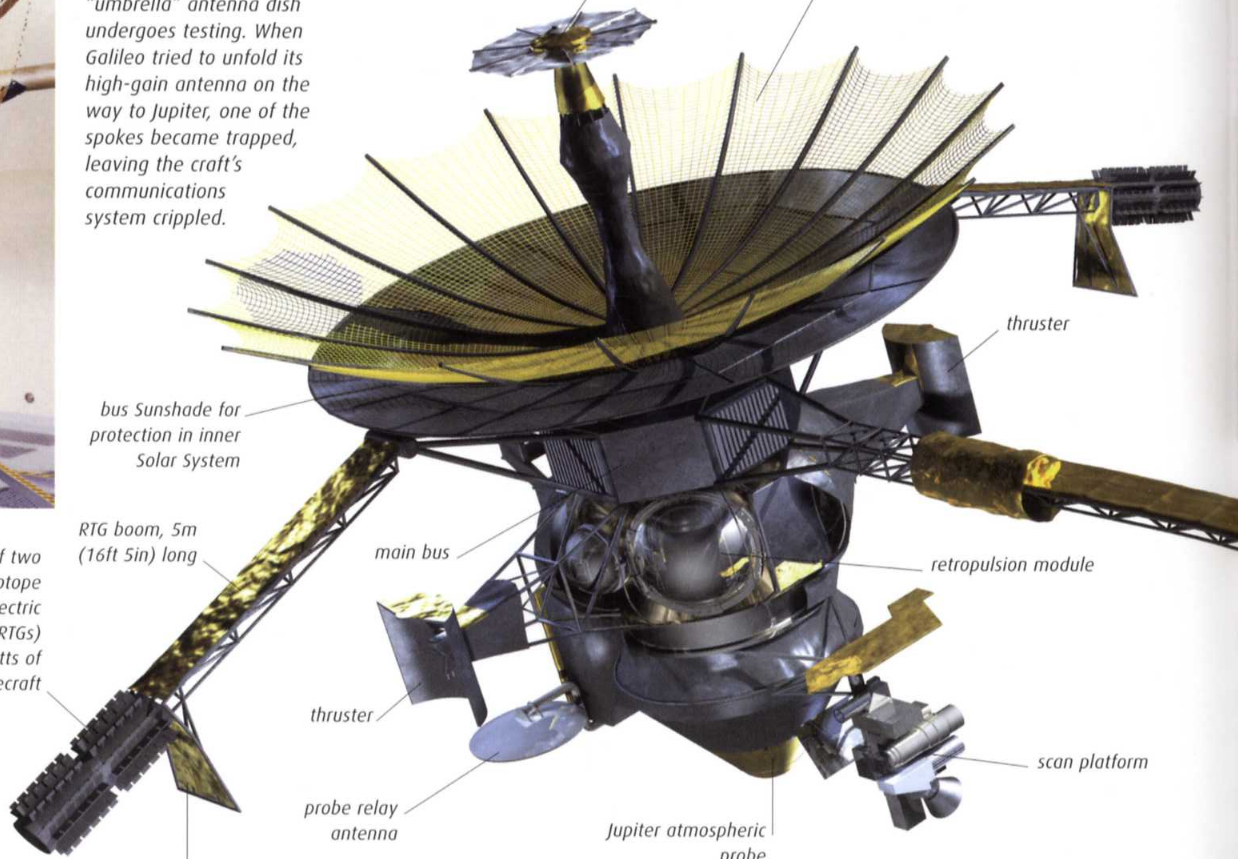
SYNTHETIC APERTURE RADAR

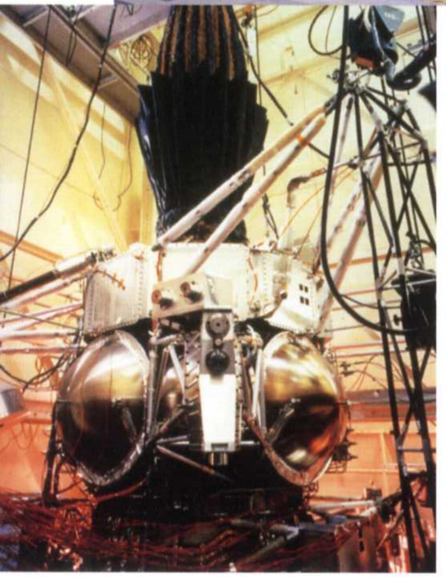
More often used on Earth satellites, SAR uses the speed at which a satellite travels along its orbit to produce radar images with higher resolutions. Instead of a single "ping", each SAR pulse is a longer "chirp" that varies its frequency over time. As the echoes of the chirp return to the satellite, it moves along a significant track through space. By identifying which parts of the chirp returned at what point on the track, a detailed picture of the ground below can be generated.



SIF AND GULA MONS
Altimetry data and other information from Magellan were combined to produce 3-D visualizations and flyovers of the Venusian terrain. This area of the Eistla Regio highlands is dominated by two huge volcanoes and a vast plain of solidified lava.

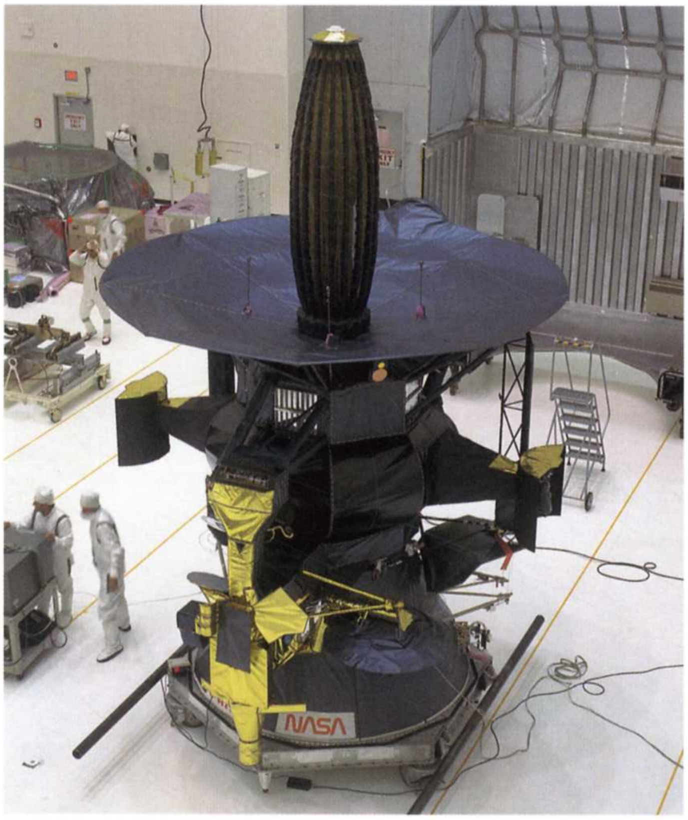
BROKEN ANTENNA
Galileo's main high-gain "umbrella" antenna dish undergoes testing. When Galileo tried to unfold its high-gain antenna on the way to Jupiter, one of the spokes became trapped, leaving the craft's communications system crippled.





DEVELOPMENT TESTS
Before any spaceprobe is built, numerous mock-ups are produced to test how it might operate in outer space. Here, a model of Galileo is shown in its launch configuration at the JPL facility.

HEIGHT	5.3m (17ft 5in)
NUMBER OF INSTRUMENTS	10 on orbiter spacecraft
TOTAL MASS	2,223kg (4,900lb)
POWER SOURCE	2 x 7.8kg (17.2lb) plutonium RTGs
MANUFACTURER	Jet Propulsion Laboratory
LAUNCH DATE	18 October 1989
TERMINATION OF MISSION	21 September 2003



READY TO GO
Galileo stands in Kennedy Space Center's Vertical Processing Facility (VPF), ready for mating with its Inertial Upper Stage booster before its 1989 launch.

TECHNOLOGY

NASA'S PROBE TO JUPITER

Galileo spacecraft

Originally known simply as the Jupiter Orbiter/Probe, Galileo, like many interplanetary orbiters, was spin-stabilized. When part of a spacecraft rotates, it acts like a gyroscope and helps to keep the craft in its desired attitude without the need for constant and wasteful corrections by the thrusters. In Galileo's case, the upper section, including antennae, field and particle experiments, and computers, rotated at three revolutions per minute. The lower section, containing cameras, other remote-sensing instruments, and the guidance sensors, kept a fixed orientation.

INSTALLATION

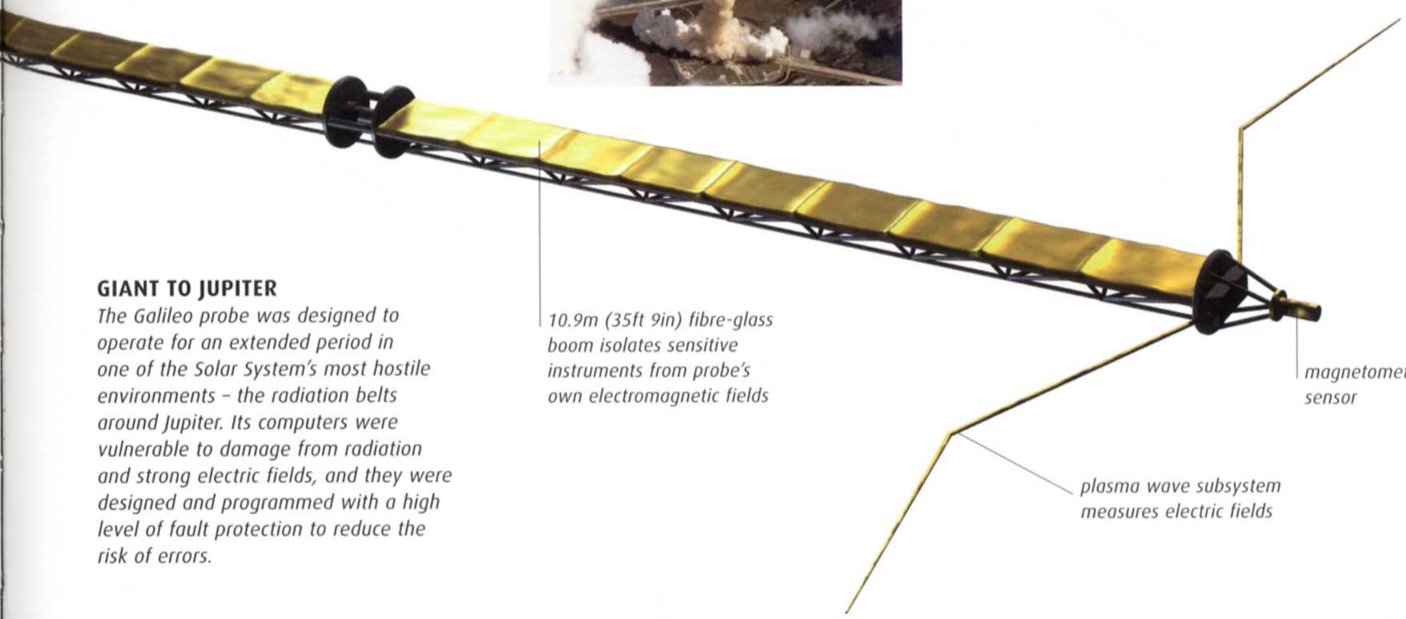
Galileo and its Inertial Upper Stage (IUS) were stowed in Atlantis's payload bay (left) prior to launch (below). The IUS attaches to a turntable that swivels upright in orbit, spins and then releases the probe.

JUPITER AT LAST

After years of delays to its proposed launch date and then a six-year journey through the Solar System, Galileo finally arrived at Jupiter on 7 December 1995 – where it would carry out eight years of work.

MONITORING GALILEO

Mission Control was at the Jet Propulsion Laboratory in Pasadena, California. During the long cruise to Jupiter, the controllers found a way to compensate for the crippled antenna on Galileo.



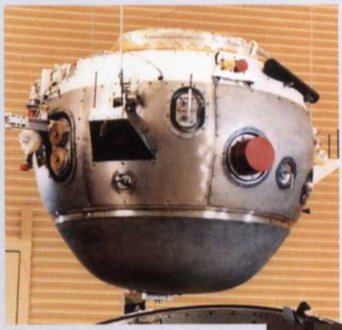
GIANT TO JUPITER

The Galileo probe was designed to operate for an extended period in one of the Solar System's most hostile environments – the radiation belts around Jupiter. Its computers were vulnerable to damage from radiation and strong electric fields, and they were designed and programmed with a high level of fault protection to reduce the risk of errors.

THE JUPITER ATMOSPHERIC PROBE

Galileo's probe was designed to plunge into the giant planet's upper cloudtops, sending data back to the orbiter as it fell. Like the main spacecraft, it used spin to stabilize its motion through space – the spacecraft itself was deliberately spun up to a higher rate prior to the probe's release. After a journey of almost five months, the probe entered the Jovian atmosphere. A heat shield protected it for the first three minutes of entry, then fell away as the drogue and then the main parachute deployed. The probe transmitted data back to the orbiter for some 59 minutes before contact was lost.

DIAMETER	1.3m (4ft 3in)
NUMBER OF INSTRUMENTS	6
TOTAL MASS	339kg (746lb)
POWER SOURCE	Onboard battery
MANUFACTURER	German Space Agency
DEPLOYMENT DATE	13 July 1995
JUPITER ATMOSPHERE ENTRY	7 December 1995

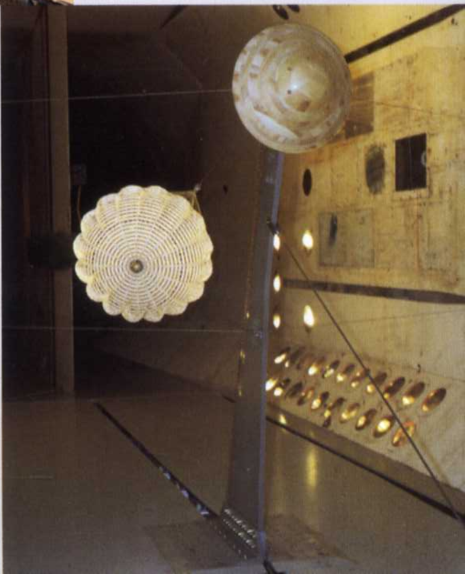


DESCENT MODULE

Tested in a specially designed "Giant Planet Facility", the probe was built to withstand the forces of Jovian gravity, heat, and atmospheric pressure.

PARACHUTE TESTING

The braking characteristics of the probe's parachute were tested in the wind tunnels at NASA's Langley Center. However, it eventually deployed a minute later than planned. Afterwards, technicians diagnosed a wiring fault – it was fortunate that the parachute opened at all.



Galileo to Jupiter

The Voyager probes had provided a tantalising taste of Jupiter and its varied moons. The next challenge was to put a probe into orbit around the giant planet and conduct a long-term study of the Jovian system.

LAUNCHED BY SHUTTLE
The Shuttle Atlantis *blasts off from Cape Canaveral on 18 October 1989, carrying Galileo at the start of its long journey to Jupiter.*

13 July 1995
Galileo releases its atmospheric probe towards Jupiter.

7 December 1995
The atmospheric probe enters Jupiter's atmosphere, sending back data for 59 minutes.

7 December 1997
After two years, Galileo completes its primary mission and moves into an extended phase, making closer flybys of Io and Europa.

7 December 1999
The Galileo mission enters a new phase known as the Galileo Millennium Mission.

30 December 2000
The Saturn-bound Cassini probe makes its closest approach to Jupiter, and mission controllers use both probes to study Jupiter simultaneously.

15 October 2001
Galileo makes its closest flyby of Io, passing just 180km (112 miles) above the surface.

21 September 2003
Galileo plunges into the Jovian atmosphere and is destroyed.

Although it did not reach Jupiter until 1995, the Galileo probe had a long gestation. Development of a Jupiter orbiter spacecraft with an atmospheric probe began even before the launch of the Voyagers in 1977. Germany joined the project in the same year, providing Galileo's propulsion systems in return for participation in the scientific programme.

Even after it was ready for launch, Galileo suffered a series of delays that ultimately pushed the mission back by eight whole years. At first, it was to be deployed in 1981, but the Space Shuttle's teething troubles put paid to that plan. The launch was rescheduled for 1984, but debates about how to boost the probe from Earth orbit saw it miss that chance. Finally scheduled for a May 1986 launch, Galileo then fell victim to the delays following the *Challenger* disaster. It set off at last in October 1989.

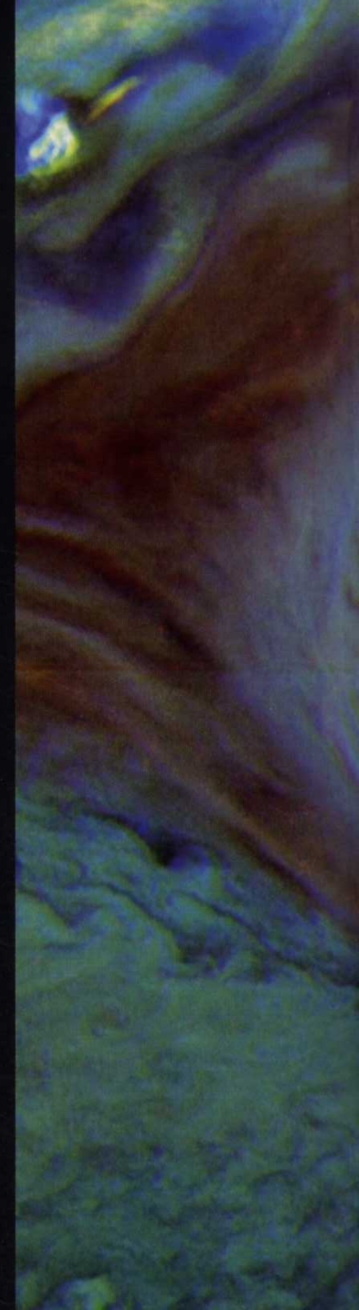
VOLCANO WORLD
Galileo's pictures of Io revealed that it is peppered with countless volcanoes and coloured by sulphur compounds from their eruptions. All this volcanic activity is driven by tidal forces from nearby Jupiter.

Planetary pinball

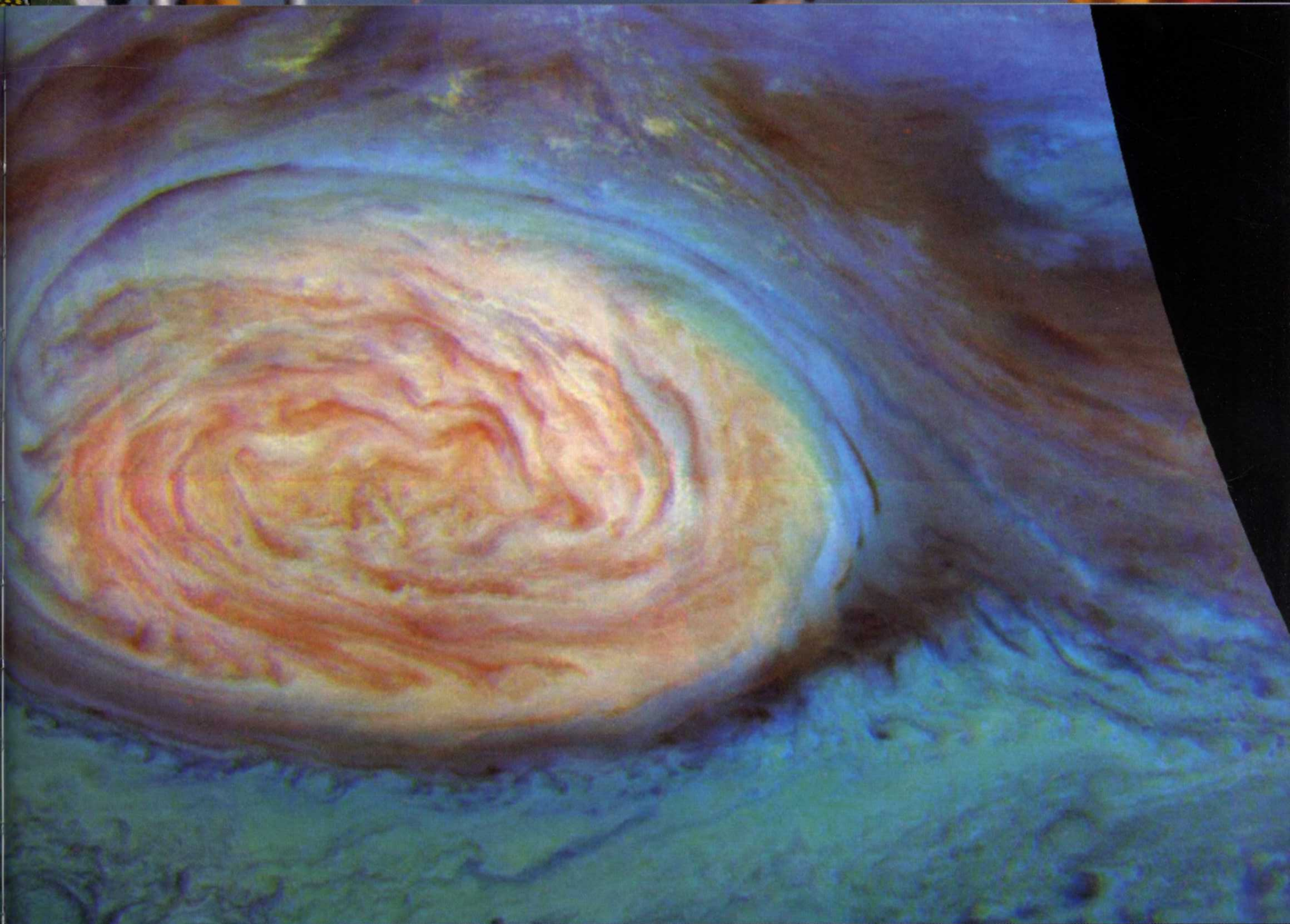
Safety restrictions introduced after *Challenger* limited the size of Galileo's booster rocket, so in order to get up speed for the trip to Jupiter, it was sent through a tortuous series of gravity assists involving a flyby of Venus and two further flybys of Earth. This Venus-Earth-Earth Gravity Assist (VEEGA) put Galileo on course to reach its target six years after its launch.

Even while the probe was on its long flight to Jupiter, its controllers and technicians were kept busy. Following the first Earth flyby, Galileo's high-gain antenna was supposed to unfold in order to allow long-distance communication, but the mechanism jammed and it was rendered useless. For a while, it looked as if Galileo might be an expensive failure, but fortunately the engineers found a way to send data through the emergency low-gain antenna at a slower rate. Galileo's onboard computers and the Earth-based receivers had to be reprogrammed to handle the new procedures. With this problem solved, Galileo was directed towards close encounters with two asteroids as it passed through the asteroid belt between Mars and Jupiter (see p.272). Then, while the probe was

LAUNCH FROM *ATLANTIS*
Deployment from the Shuttle meant that Galileo could only use an Inertial Upper Stage booster rocket, instead of a powerful Centaur upper stage that would have allowed a more direct route to Jupiter.



GREAT INFRARED SPOT
Galileo's infrared cameras allowed it to map the depth of Jupiter's clouds. In this image of the famous Great Red Spot, deep clouds are colour coded blue and black, dense high clouds are white, and high thin hazes are pink.



still a year from Jupiter, it had a spectacular view when Comet Shoemaker-Levy crashed into the giant planet in July 1994. Arriving at last, Galileo fired its main engine and dropped into orbit around Jupiter. During final approach, the atmospheric probe was released from the main spacecraft and plunged into the atmosphere (see panel, right).

Eight years of discovery

Now Galileo began its long scientific mission. It orbited Jupiter roughly once every two months, on long ellipses that brought it close to all of the major moons. The original plan for the mission assumed the probe might function for about two years – Jupiter is surrounded by radiation belts far fiercer than those around the Earth, which damage even the most robust electronics over time. As it was, Galileo beat even the most optimistic forecasts, surviving for more than eight years.

Over time, the probe was gradually brought closer to Jupiter itself, spending more time in the radiation zone. A final series of close encounters with Io saw its cameras damaged beyond repair in January 2002. During its time in orbit, Galileo had revolutionized ideas about the Jupiter system. In particular, it had revealed the huge extent of volcanic eruptions on Io (now known to be the most volcanic world in the Solar System) and bolstered the evidence that Europa's crust of scarred ice hides a global saltwater ocean kept warm by volcanic activity. Such an ocean might even harbour life, and in order to prevent contamination Galileo was steered to a fiery end in Jupiter's atmosphere on 21 September 2003.

ICY EUROPA
Europa's brown stains are thought to show where its icy crust has cracked, allowing chemical-laden water to seep in and heal the scars.

TECHNOLOGY

THE PROBE'S STORY

Galileo's atmospheric probe entered the Jovian atmosphere at a speed of 47km (29 miles) per second. As it fell, it was slowed to below the speed of sound (0.35km/0.2 miles per second) in just two minutes. Friction with the atmosphere turned the probe into a flaming bullet and burned away more than half the mass of its 152kg (334lb) heat shield. Only then did the probe deploy its parachute and begin transmitting data. Fifty-nine minutes of temperature and pressure information were relayed via the main Galileo spacecraft to Earth, along with information about the chemical composition of the atmosphere, which turned out to be drier than expected, with less water vapour. The probe finally overheated and stopped transmitting at a depth of 146km (91 miles).

March 1986
A series of five spaceprobes study Halley's Comet during its passage round the Sun.

29 October 1991
The Galileo Jupiter probe makes the first asteroid flyby, of 951 Gaspra.

14 February 2000
NEAR arrives in orbit around asteroid 433 Eros.

14 February 2001
NEAR touches down on the surface of Eros at the end of its mission.

2 January 2004
NASA's Stardust flies through the coma of Comet Wild 2 and collects samples of comet dust.

2 March 2004
ESA's Rosetta probe is launched on a ten-year journey to rendezvous with a comet beyond the orbit of Mars.

4 July 2005
Deep Impact launches its projectile into Comet Tempel 1 and studies the resulting explosion.

19 November 2005
The Japanese Hayabusa probe touches down on asteroid 25143 Itokawa and attempts to collect material from the surface.

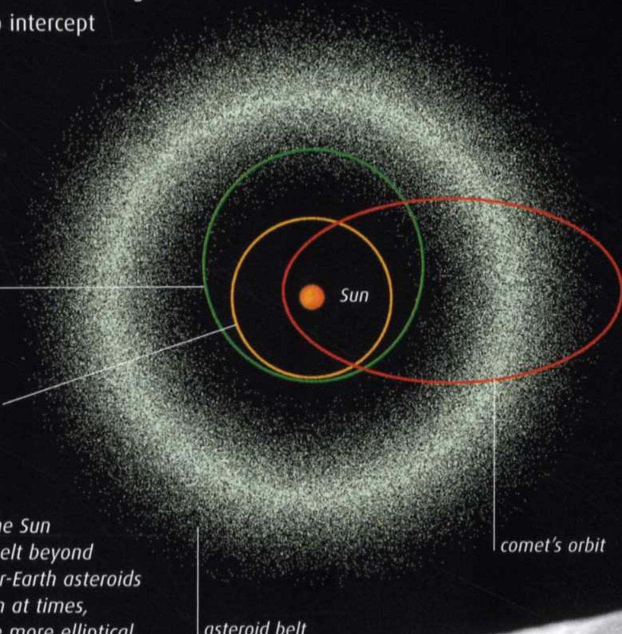
Comets and asteroids

The smaller worlds of the Solar System hold the answers to many of the questions about its origins – and since the 1980s they have been visited by a wide variety of spaceprobes.

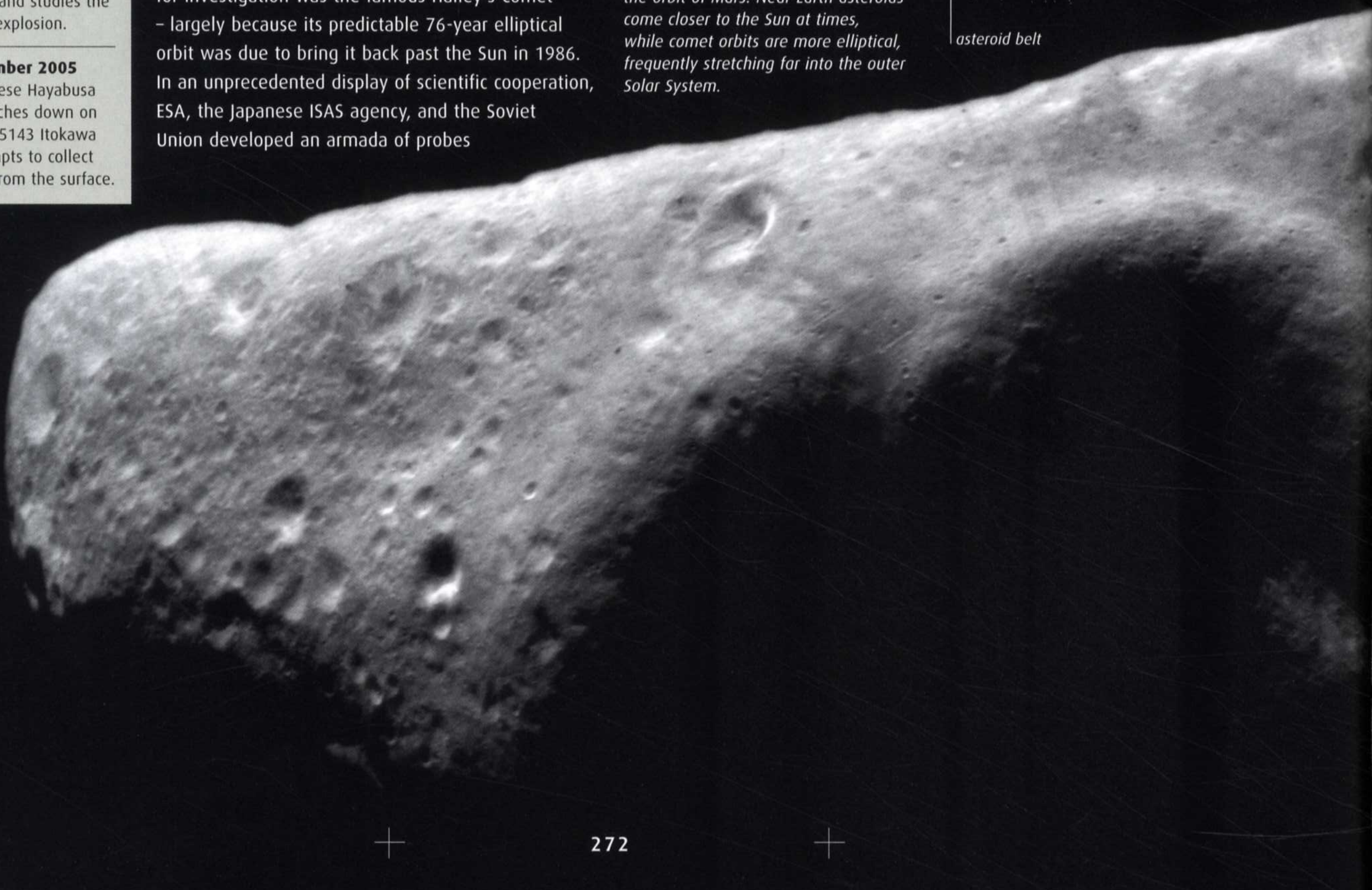
Between and beyond the orbits of the eight major planets there are countless small objects, ranging in size from mere boulders to minor worlds comparable to our Moon. The largest of these are icy dwarf planets that lurk within the Kuiper Belt beyond the orbit of Neptune (see p.306). Closer to the Sun, the objects are generally rockier and are known as asteroids. Comets are occasional visitors from the outer Solar System – irregular chunks of rock and ice following long elliptical orbits, which only develop their familiar tails when they are heated by the Sun. Both comets and asteroids are thought to preserve pristine material from the dawn of the Solar System, unaffected by the geological and chemical processes that have helped to shape the larger planets and moons. This makes them important targets for unmanned spacecraft.

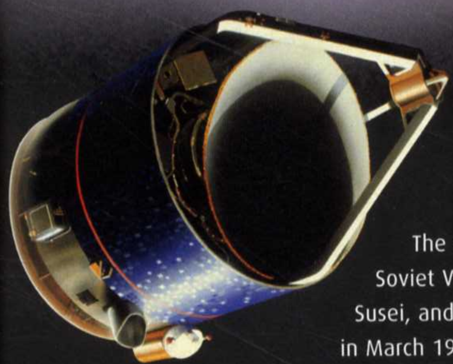
Early investigations

The first of these small worlds to be targeted for investigation was the famous Halley's Comet – largely because its predictable 76-year elliptical orbit was due to bring it back past the Sun in 1986. In an unprecedented display of scientific cooperation, ESA, the Japanese ISAS agency, and the Soviet Union developed an armada of probes to investigate different aspects of the comet. NASA did not participate but laid a claim to the first comet probe by diverting ISEE-3, a satellite already studying the solar wind of particles blowing out from the Sun, to intercept Comet Giacobini–Zinner in 1985 – it became known as the International Cometary Explorer.



VARIED ORBITS
Most asteroids orbit the Sun in the main asteroid belt beyond the orbit of Mars. Near-Earth asteroids come closer to the Sun at times, while comet orbits are more elliptical, frequently stretching far into the outer Solar System.



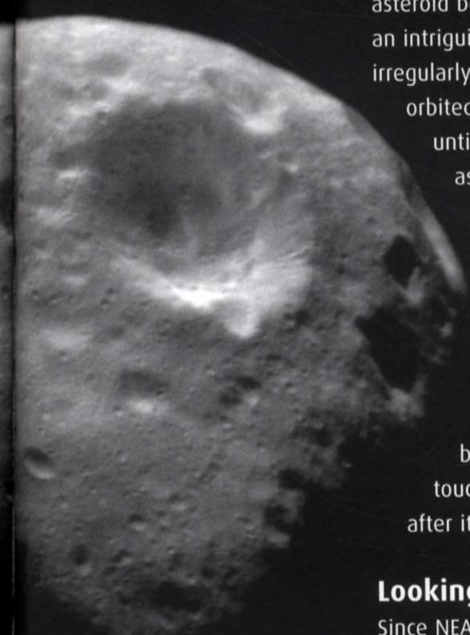


GIOTTO TO HALLEY
The Giotto probe (above), launched in 1985 on an Ariane 1 rocket, was battered by high-speed dust particles on its final approach to the nucleus of Halley's Comet (top).

The armada of probes sent to Halley – the Soviet Vegas 1 and 2, the Japanese Sakigake and Susei, and Europe's Giotto – all flew past the comet in March 1986, when it was at its most active. Their data helped to build a comprehensive picture of the comet, but Giotto had the most spectacular success, sending back pictures of the comet's "dirty snowball" nucleus from just 600km (370 miles) away.

Orbiting an asteroid

The first close-up studies of asteroids were made by the Galileo probe as it passed through the main asteroid belt on its way to Jupiter. Pictures provided an intriguing glimpse of elongated Gaspra and the irregularly shaped Ida, which Galileo revealed was orbited by a tiny moon, Dactyl. But it was not until 1996 that a spaceprobe dedicated to asteroid research was launched. This was NEAR, the Near Earth Asteroid Rendezvous mission. After a long journey, it slipped into orbit around asteroid 433 Eros, arriving appropriately on Valentine's Day, 14 February 2000. Over the following months, NEAR mapped and probed Eros with a variety of instruments, before it was finally guided to a gentle touchdown on the surface one year to the day after its arrival.



Looking inside

Since NEAR, studies of comets and asteroids have accelerated, with a wide range of missions to study their properties. Several of these were developed under NASA's Discovery programme – a series of spaceprobes with very specific objectives that followed a new "faster, better, cheaper" philosophy.

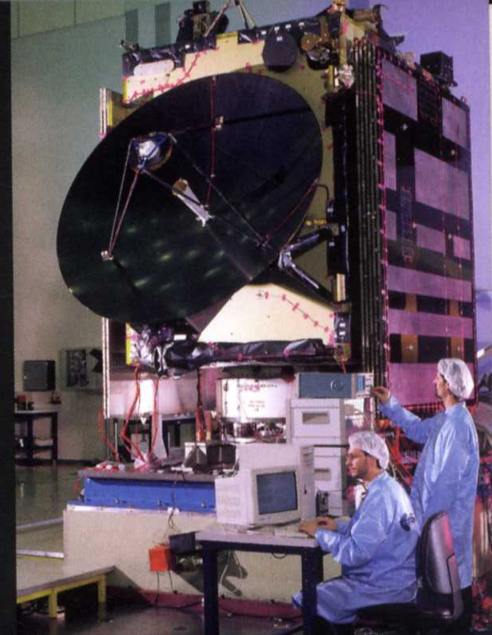
Stardust was the first to be launched, in February 1999. Its mission was to rendezvous with Comet Wild 2, collecting a sample of particles from the comet's coma on a lightweight material called an aerogel. Stardust then looped back to Earth in 2006, and ejected its precious cargo in a re-entry capsule.

Another impressive NASA mission was the appropriately named Deep Impact. This time, the objective was to fire a barrel-like 370kg (814lb) projectile into a comet and study the material that was flung into space. The data from the spectacular impact on Comet Tempel 1 in July 2005 caught many scientists by surprise and led to a rethink of previous comet models – Tempel 1 turned out to be far more dusty, and less icy, than expected.

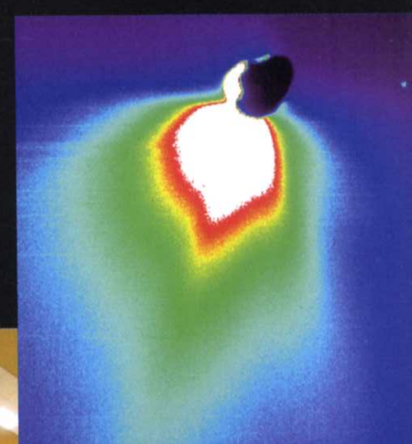
Japan's JAXA launched its own ambitious Hayabusa probe in May 2003. Hayabusa aimed to touch down on the surface of the near-Earth asteroid 25143 Itokawa, collect samples of material, lift off, and return to Earth. Although the mechanism intended to blast material from the surface of Itokawa failed, there is some hope that the collection system may still have swept up some floating dust – we will know for sure only after Hayabusa releases its re-entry capsule in June 2010.

Perhaps the most ambitious of all the recent comet probes, however, is ESA's Rosetta. Launched in 2004, it will rendezvous with Comet Cheryumov-Gerasimenko in 2014, deploy a small lander called Philae onto its surface, and then orbit the comet as it falls back towards the Sun, heats up, and becomes active.

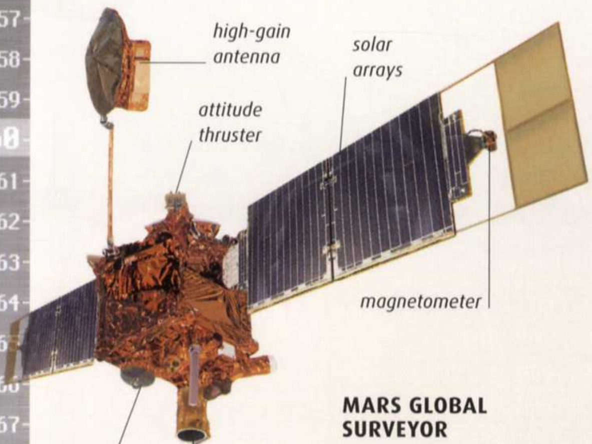
ASTEROID EROS
NEAR's images of Eros revealed a surprisingly smooth surface. Scientists believe that a major impact around a billion years ago sent shock waves along the entire 31-km (19¼-mile) length of Eros, shaking up and evening out the surface.



COMET CHASER
Engineers at ESA's European Space Research and Technology Centre in the Netherlands prepare to test the Rosetta probe's tolerance to high and low temperatures. As it follows its target comet from beyond the orbit of Mars around the Sun, it will be exposed to both extremes.



MISSION DEEP IMPACT
(Left) The Deep Impact flyby spacecraft is stacked with the impactor prior to launch.
(Above) Fifty minutes after the impact on Comet Tempel 1, the flyby spacecraft captured this image of a plume of gas and dust rising above the limb of the comet – the colours represent the brightness of materials in the comet.



Return to Mars

After a break in Martian exploration of almost two decades, the late 1990s saw the beginning of a new wave of more sophisticated probes – orbiters, landers, and rovers that have transformed our view of the Red Planet.

MARS GLOBAL SURVEYOR
The thrusters on MGS were able to tilt the probe 30° in any direction to photograph the Martian surface at oblique angles, and even look at objects close to Mars such as its two small moons and other orbiting spacecraft.

4 July 1997
Mars Pathfinder and its Sojourner Rover touch down on Mars.

12 September 1997
Mars Global Surveyor (MGS) enters orbit and begins aerobraking.

1 April 1999
MGS begins its primary mission.

23 September 1999
Mars Climate Orbiter crashes into the planet during orbit insertion.

3 December 1999
Mars Polar Lander is lost shortly before landing on the planet.

24 October 2001
Mars Odyssey enters orbit and begins aerobraking.

25 December 2003
Mars Express enters orbit. Beagle 2 drops into the Martian atmosphere but fails during landing.

4 January 2004
The Spirit Mars Exploration Rover lands in Gusev Crater.

25 January 2004
The Opportunity Mars Exploration Rover lands in Meridiani Planum.

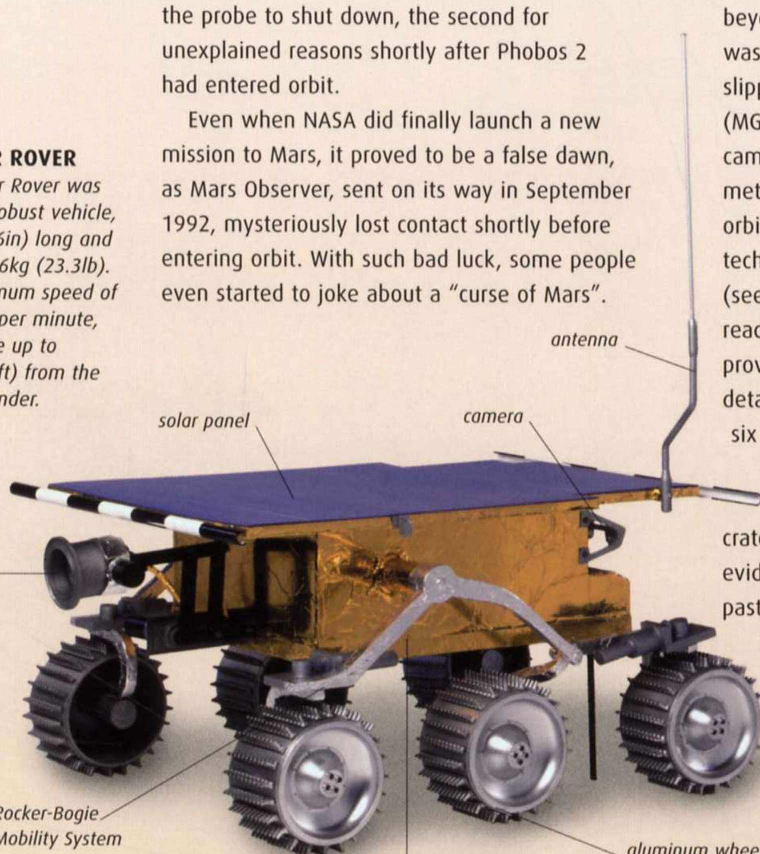
The 1980s and early 1990s were a bad time for Mars-bound spaceprobes. NASA's immediate plans to follow up on the success of Viking were shelved as the rising cost of the Space Shuttle programme forced cutbacks elsewhere, and a series of Soviet probes fell victim to a variety of accidents and mishaps. For example, two sophisticated Phobos probes were lost in the late 1980s – the first when a faulty signal from Earth accidentally ordered the probe to shut down, the second for unexplained reasons shortly after Phobos 2 had entered orbit.

Even when NASA did finally launch a new mission to Mars, it proved to be a false dawn, as Mars Observer, sent on its way in September 1992, mysteriously lost contact shortly before entering orbit. With such bad luck, some people even started to joke about a "curse of Mars".

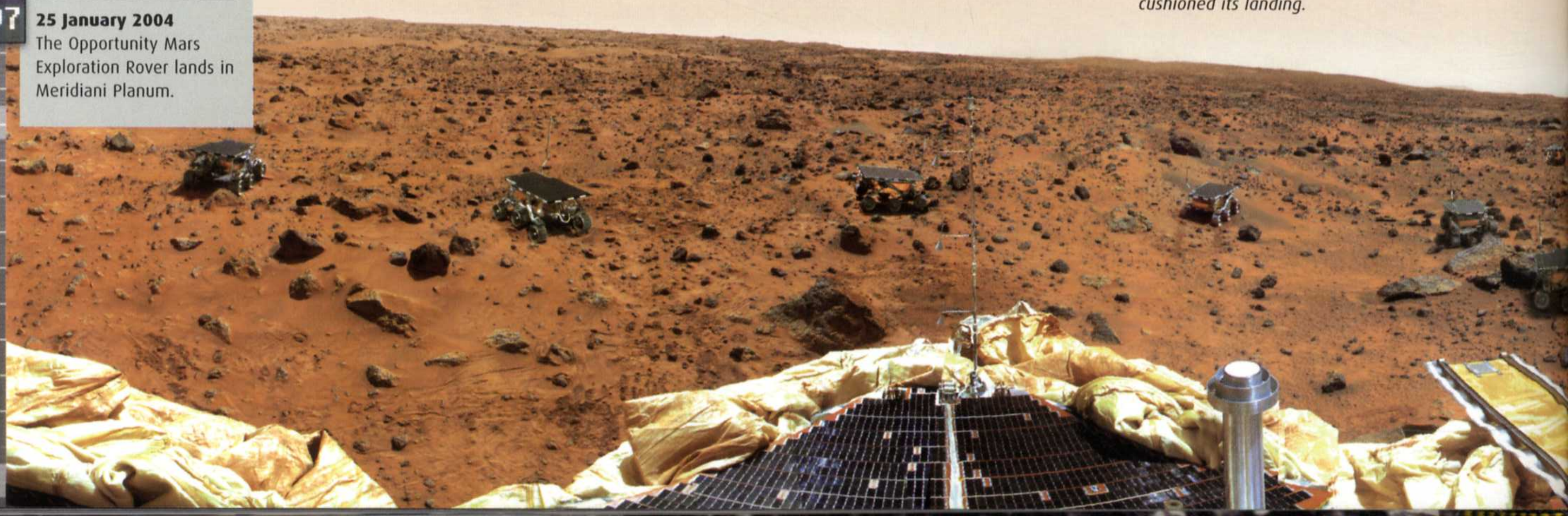
The long wait ends

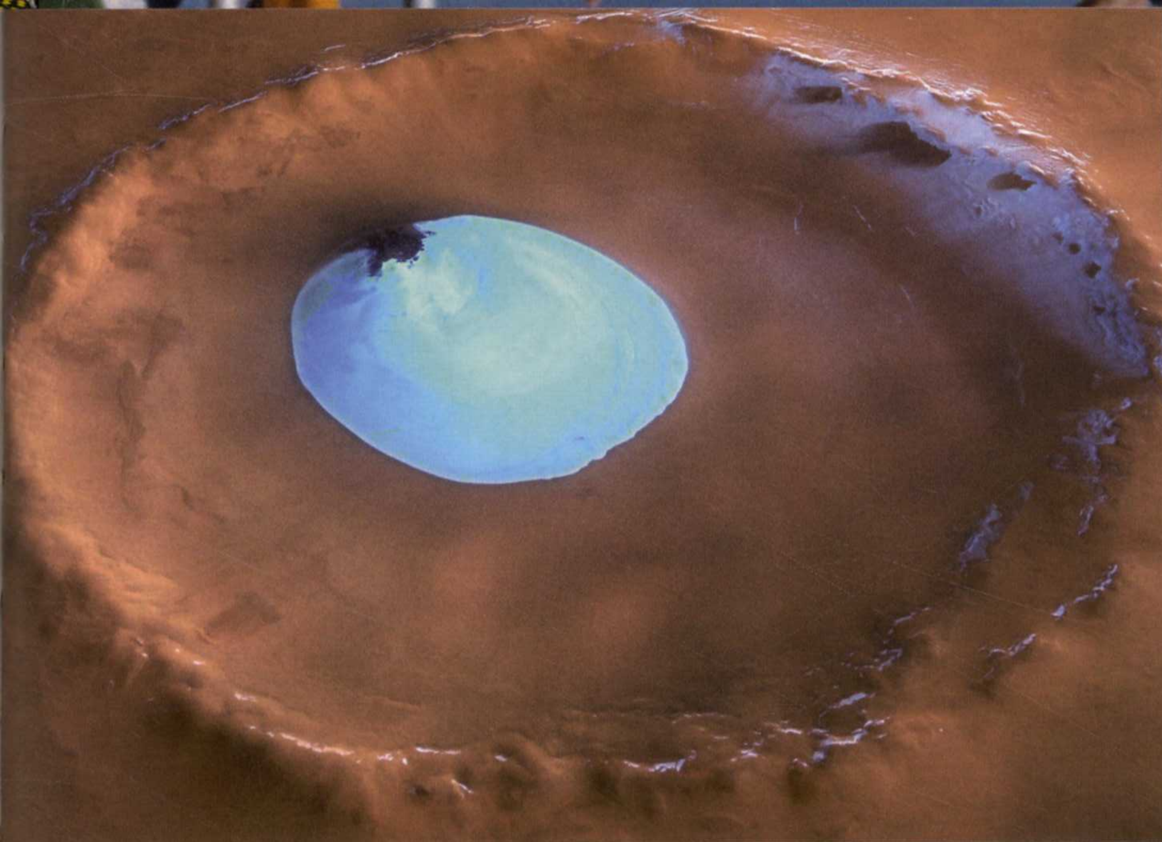
It was not until 1997 that a relatively small spacecraft, Mars Pathfinder, finally touched down in the Ares Vallis region. As the probe unfolded its triangular, petal-like solar panels, it released a small rover called Sojourner, which trundled onto the Martian soil on 4 July and immediately began to explore the rocky landscape around it. Sojourner operated for 83 Martian days, well beyond its expected lifetime, and even while it was still roaming the surface, another mission slipped into orbit above it. Mars Global Surveyor (MGS) brought with it sophisticated, high-resolution cameras that could distinguish objects just a few metres across. In order to slow itself into a lower orbit, however, the probe used the aerobraking technique rehearsed by the Magellan Venus mission (see p.266), slowly spiralling inwards until it was ready to begin its serious work in April 1999. MGS provided a stunning new view of Mars, sending back detailed pictures for some seven-and-a-half years – six years beyond its primary mission. Perhaps its most important revelation was the presence of eroded gullies on some canyon slopes and crater walls, which many experts believe are evidence of liquid flowing on Mars in the very recent past. Elsewhere, the presence of near-pristine lava flows suggested that Mars may still have volcanic activity too.

SOJOURNER ROVER
The Sojourner Rover was a small but robust vehicle, just 65cm (26in) long and weighing 10.6kg (23.3lb). With a maximum speed of 60cm (24in) per minute, it could range up to 500m (1,650ft) from the Pathfinder lander.



PRESIDENTIAL PANORAMA
A mosaic of photographs from the Mars Pathfinder lander, this so-called Presidential Panorama includes ten separate images of the Sojourner Rover investigating the nearby landscape. The lander itself is surrounded by the deflated airbags that cushioned its landing.



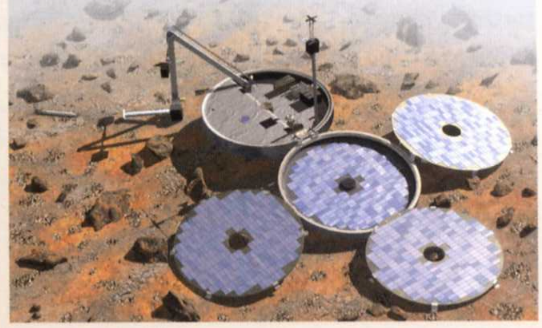


MARS IN STEREO
The stereoscopic camera on Mars Express produced spectacular 3-D images such as this one of ice trapped in a deep crater. The probe itself (right) was rapidly designed using the same basic spacecraft as the Rosetta comet probe.

TECHNOLOGY

THE ILL-FATED BEAGLE

Beagle 2 (named after the ship on which naturalist Charles Darwin travelled) was a small probe designed specifically to look for signs of life on Mars. The probe separated from the Mars Express orbiter on 19 December 2003 and entered the atmosphere on Christmas Day. It was supposed to touch down in the equatorial region of Isidis Planitia, open up, and use a robot arm to collect rock samples for analysis in various instruments. But nothing was heard from the Martian surface – it seems likely that Beagle 2 was disabled by hitting a crater wall as it landed.



As NASA accelerated its programme of Martian probes, bad luck struck again – Mars Polar Lander, which should have investigated the planet's southern ice cap, was lost just before entering the atmosphere in December 1999, while Mars Climate Orbiter hit the planet after an embarrassing navigational error.

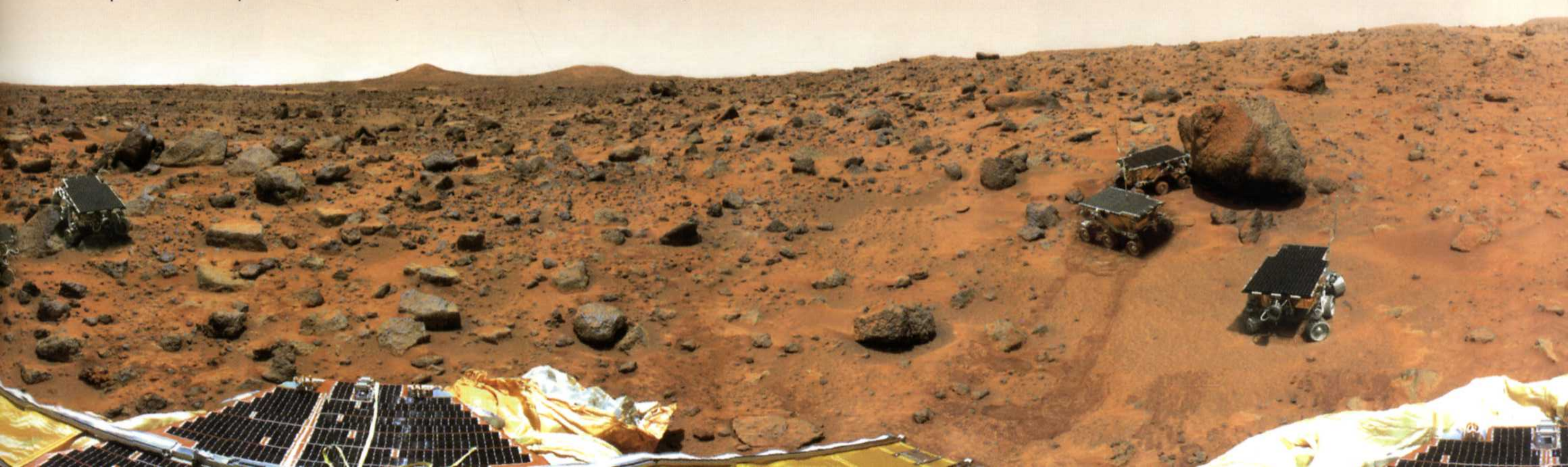
Two years later, 2001 Mars Odyssey reached orbit successfully. Designed to complement MGS, Odyssey included imagers and spectrometers to study Mars at different wavelengths and probe the chemicals in its rocks. Its most important finding was probably the presence of huge amounts of hydrogen (probably in icy permafrost) around both poles.

Europe goes to Mars

ESA's first interplanetary probe, Mars Express, arrived at the Red Planet on Christmas Day 2003. The probe had two parts – the Mars Express Orbiter and a small, and ultimately doomed, British-built lander called Beagle 2 (see panel, above). The orbiter carried spectrometers to investigate the chemistry of the Martian surface and atmosphere, a ground-penetrating radar to study buried features, and a camera that produced three-dimensional views by photographing areas of the surface from two slightly different angles. Mars Express's most important finding so far is the presence of methane in the Martian atmosphere. It seems this gas can come from only two sources – either active volcanoes or some form of life.

In 2004, two new NASA rovers arrived on Mars (see over). Larger and more robust than Sojourner, these Mars Exploration Rovers, Spirit and Opportunity, sent their data back to Earth directly or relayed through the MGS and Odyssey orbiters. Spirit's landing site in Gusev Crater had a broad, river-like channel flowing into it, and scientists hoped that the terrain might be covered in sedimentary rocks laid down by dust settling out of a standing lake. But surprisingly, the rocks turned out to be mostly volcanic.

Opportunity's landing site in Meridiani Planum was thought to lie near the shore of an ancient shallow sea, and when the probe visited a small nearby crater its operators were delighted to find sedimentary rocks in its walls and traces of minerals that probably formed under water. Despite gradual deterioration due to a build up of fine Martian dust, the rovers were still functioning three years after their arrival.

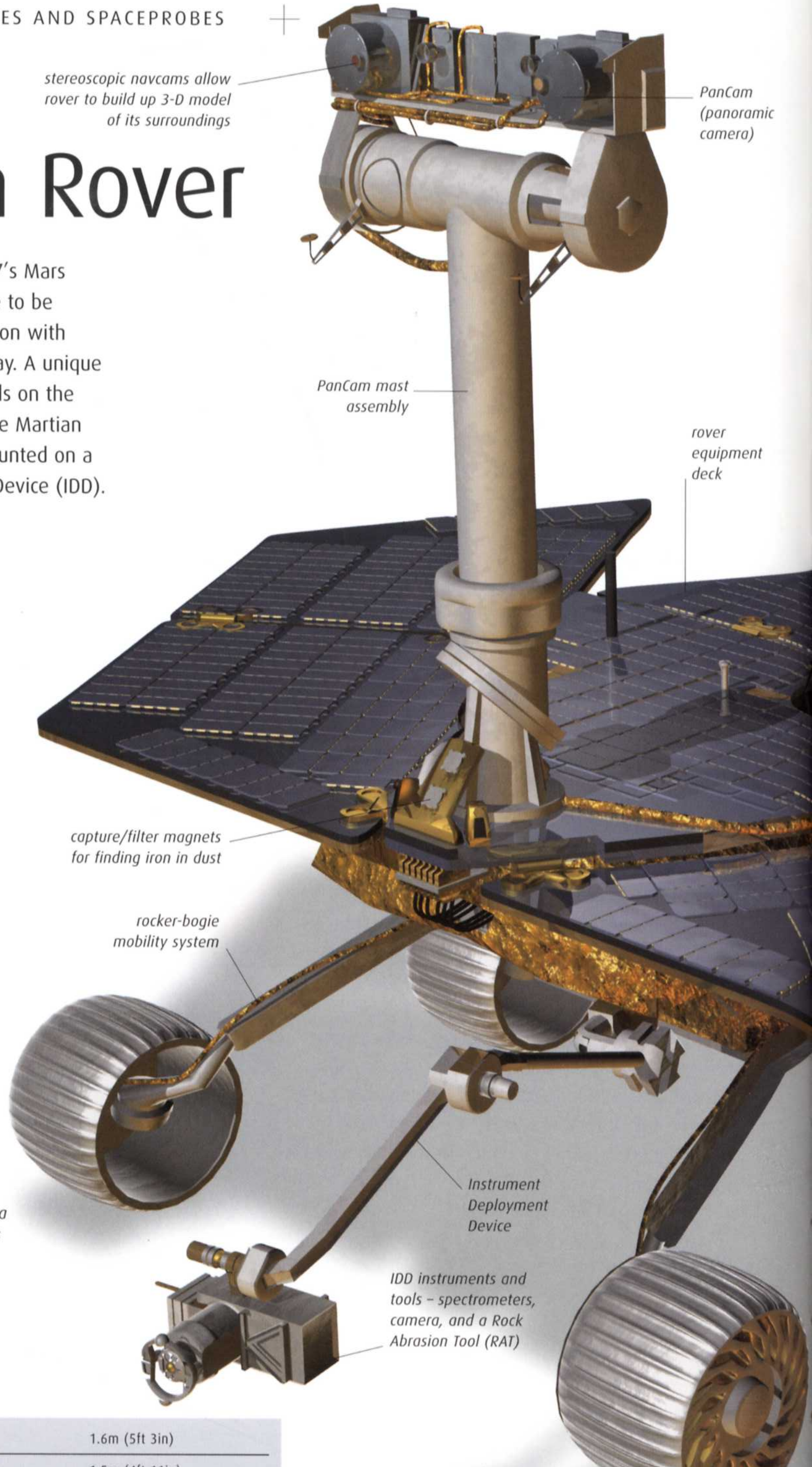


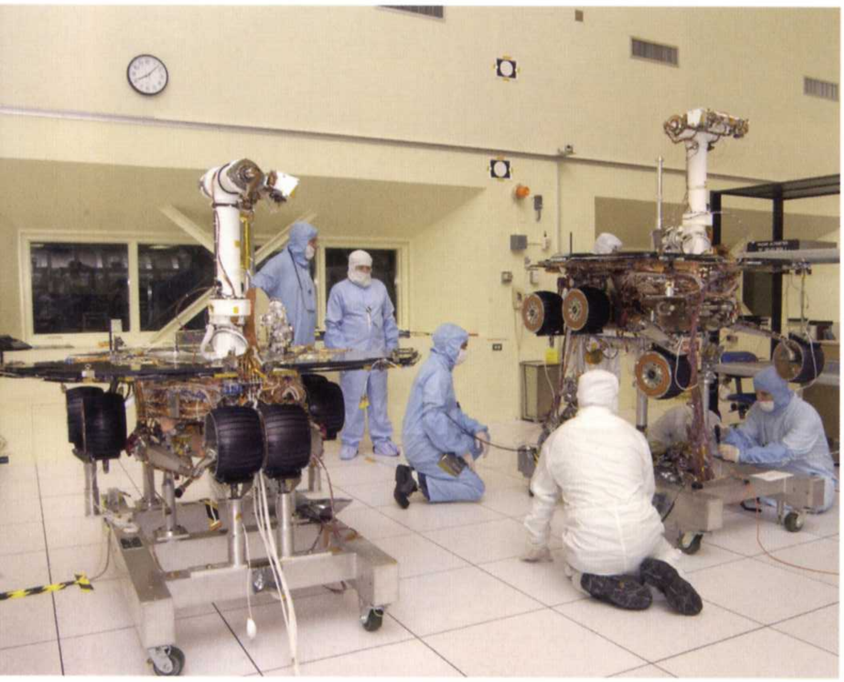
TECHNOLOGY

NASA'S SPIRIT AND OPPORTUNITY

Mars Exploration Rover

NASA's second generation of Mars rovers built on the success of 1997's Mars Pathfinder mission. But the two Mars Exploration Rovers (MERs) were to be much larger and more robust vehicles, capable of direct communication with Earth or the various Martian orbiters without using a base-station relay. A unique suspension and drive system, powered by a large array of solar panels on the MER's upper surface, allowed it to negotiate almost any hazard on the Martian surface with ease. Cameras and other scientific instruments were mounted on a raised mast and on a small robot arm – the Instrument Deployment Device (IDD).





TWINS
The MER rovers were built side-by-side at the Jet Propulsion Laboratory. Developing a pair of probes is always a good policy as it is a cost-effective way of doubling the science yield from a project and also helps insure against failures.

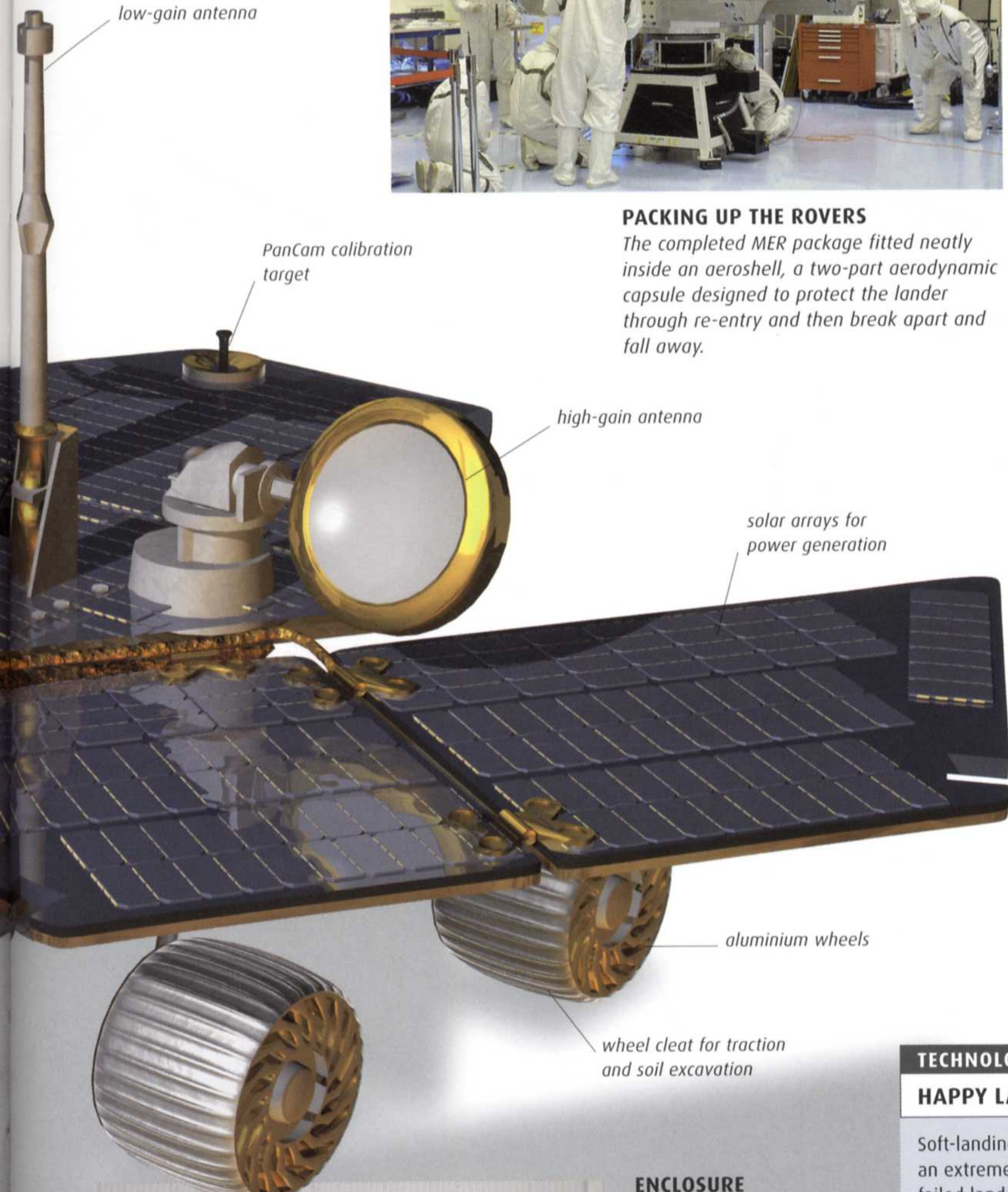
TWO GENERATIONS OF ROVER
MER meets Sojourner in the lab at JPL. The larger rover borrowed the rocker-bogie suspension system developed for Sojourner – each wheel has independent suspension and keeps contact with the ground at all times, reducing the risk of sudden bumps and shocks. The MER has rolled over large rocks and rough terrain with few problems.

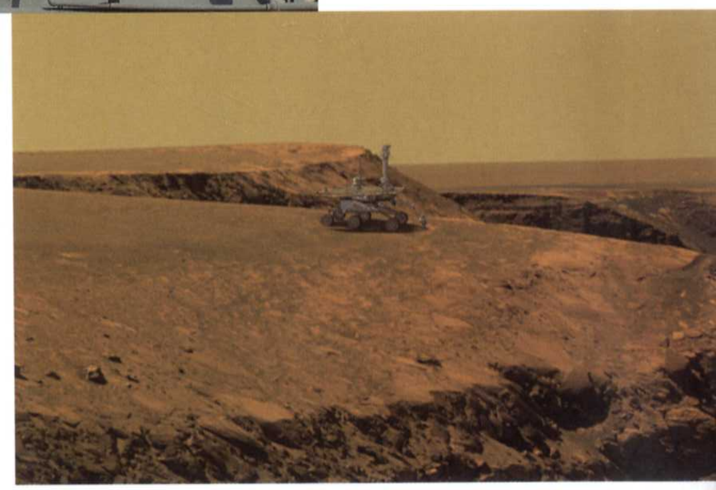
LENGTH	1.6m (5ft 3in)
HEIGHT	1.5m (4ft 11in)
WEIGHT	185kg (407lb)
NUMBER OF INSTRUMENTS	7 including PanCam
POWER SOURCE	Top-mounted solar arrays
MANUFACTURER	JPL/Caltech
LAUNCH DATES	10 June 2003 (Spirit), 8 July 2003 (Opportunity)

SLOW BUT SURE
The MER is a high-performance vehicle: independent motors on each wheel allow it to negotiate most obstacles, and it can turn on the tightest of angles. However, it is not the fastest vehicle – its top speed on Mars is about 5cm (2in) per second, and it stops every few seconds to allow its computer to study the route ahead.

PACKING UP THE ROVERS
The completed MER package fitted neatly inside an aeroshell, a two-part aerodynamic capsule designed to protect the lander through re-entry and then break apart and fall away.

READY FOR LAUNCH
The launch tower at Cape Canaveral's Pad 17-A rolls back to reveal the Delta II rocket that would launch Spirit on its way to Mars. For the seven-month journey, the aeroshell was mounted on a disc-shaped cruise stage carrying communications equipment, guidance systems, and thrusters for course adjustments en route.





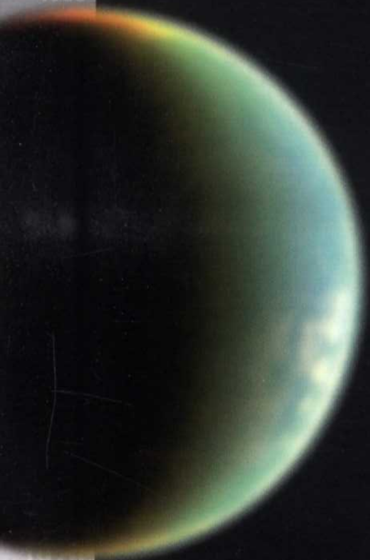
OPPORTUNITY ON MARS
An artist's impression places the Opportunity MER on the edge of a genuine photograph of Victoria Crater. The Mars Reconnaissance Orbiter spotted the rover here shortly after its arrival in 2006 (see p.283).

TECHNOLOGY

HAPPY LANDINGS

Soft-landing a robot on the surface of Mars is an extremely difficult task, as the number of failed landers attests. With just one per cent of the density of Earth's atmosphere, the Martian air is too thin for a parachute to completely slow down an incoming probe. MER combined a descent parachute with two other innovations. A cluster of airbags inflated around the lander during its final stages of descent, while a retrorocket unit suspended in-between the parachute and the cushioned lander fired just above the surface to help slow the speed of impact. Once they had stopped bouncing, the airbags deflated, and powerful motors in the lander unit's "petals" pushed the vehicle into a horizontal position.

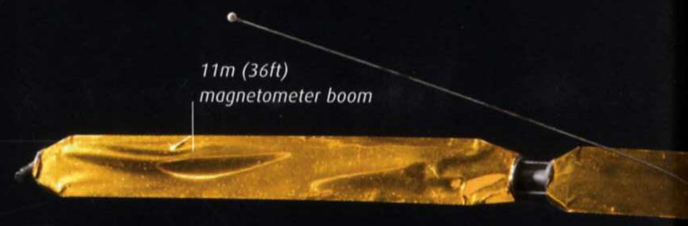
ENCLOSURE
With its solar arrays folded inwards for protection, each MER was then enclosed in a simple lander, consisting of four triangular panels that folded and joined to form a tetrahedron. This was, in turn, enclosed in the aeroshell. The airbag system that would cushion the landing (see right) was attached to the outside of the lander, and the whole MER assembly attached by tether to the retrorocket and braking parachute unit.



TITAN'S SURFACE
This composite of three infrared images from Cassini reveals details on the surface of Titan that are hidden in visible light by the opaque atmosphere.

Cassini–Huygens

The Cassini mission was the most sophisticated spaceprobe so far, designed to orbit among the moons and rings of Saturn for at least four years.



Following the Voyager encounters with Saturn in the early 1980s, it was clear that the ringed planet and its moons still held enough secrets to justify an orbiter mission similar to the Galileo one already planned for Jupiter. The project became an international effort after a committee formed to look at future collaboration between NASA and the European Space Agency ESA recommended an orbiter-and-probe mission similar to what NASA had in mind. It was named Cassini after Gian Domenico Cassini, the 17th-century Italian-French astronomer who discovered the main division within Saturn's rings.

Cassini's original design was similar to Galileo – both were to be "Mariner Mark II" craft, as was a third mission, the Comet Rendezvous Asteroid Flyby (CRAF). However, when CRAF was cancelled the idea of developing a coherent second wave of Mariner probes was abandoned, and Cassini subsequently evolved into a much larger, heavier design.

While Galileo carried an atmospheric probe to descend into Jupiter's clouds, Cassini's cargo was even more ambitious – a lander that would parachute through the murky haze of Titan and send back data and pictures from the surface. This lander, Huygens, was ESA's main contribution to the project.

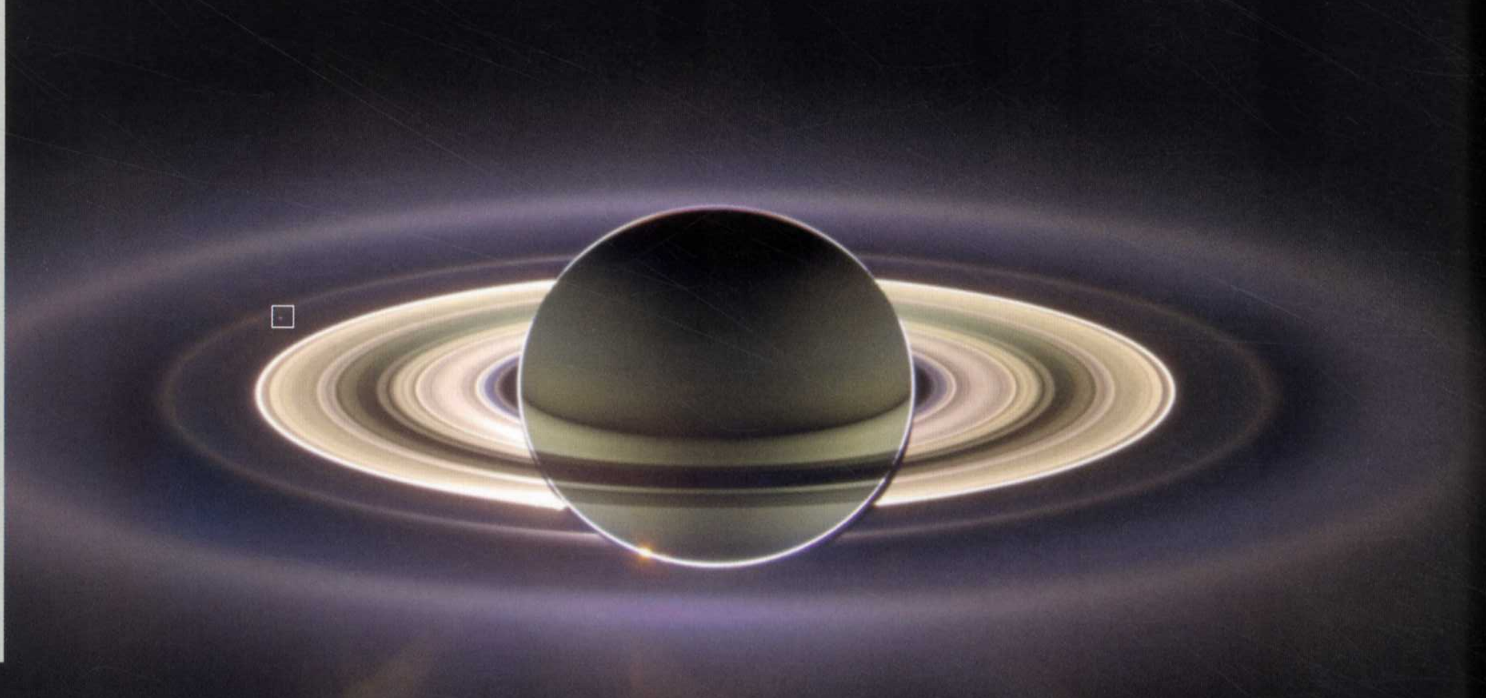
In order to power its array of scientific instruments, Cassini carried a large payload of plutonium in its radioisotope thermal generators. The possibility of an accident created much controversy before launch and during Cassini's flyby of Earth in 1999 (although smaller quantities of plutonium had already been used by previous spaceprobes). Fortunately, the launch, by a Titan IVB/Centaur rocket on 15 October 1997, went flawlessly. With a total mass at launch of 5,655kg (12,441lb), the probe was so big that it needed a complex series of gravity assists to get up to a reasonable speed. For this reason, the flight to Saturn took more than six years, with flybys of Venus (twice), Earth, and Jupiter. Cassini reached Jupiter in late 2000 and produced a unique scientific opportunity – the Saturn-bound probe was able to make long-range observations of the giant planet and its moons at the same time as Galileo.

Arrival at Saturn

Cassini's main engine executed a 96-minute burn to drop the spacecraft into orbit around Saturn on 1 July 2004. On its way into the Saturnian system, the probe had already provided the first close-up

BUILDING HUYGENS
Engineers fit the back cover to the Huygens probe. The gold tiles offered protection against the extreme temperatures encountered during entry into Titan's atmosphere.

BACKLIT RINGS
On 15 September 2006, Cassini passed into Saturn's shadow. Over three hours it took 165 images of the still-sunlit rings, resulting in this magnificent panorama. The box marks the distant glimmer of the Earth.



11 June 2004
Cassini flies by Saturn's four-billion-year-old frozen moon Phoebe.

1 July 2004
After an epic journey of over six years, which included flybys of Venus and Jupiter, Cassini finally enters orbit around Saturn.

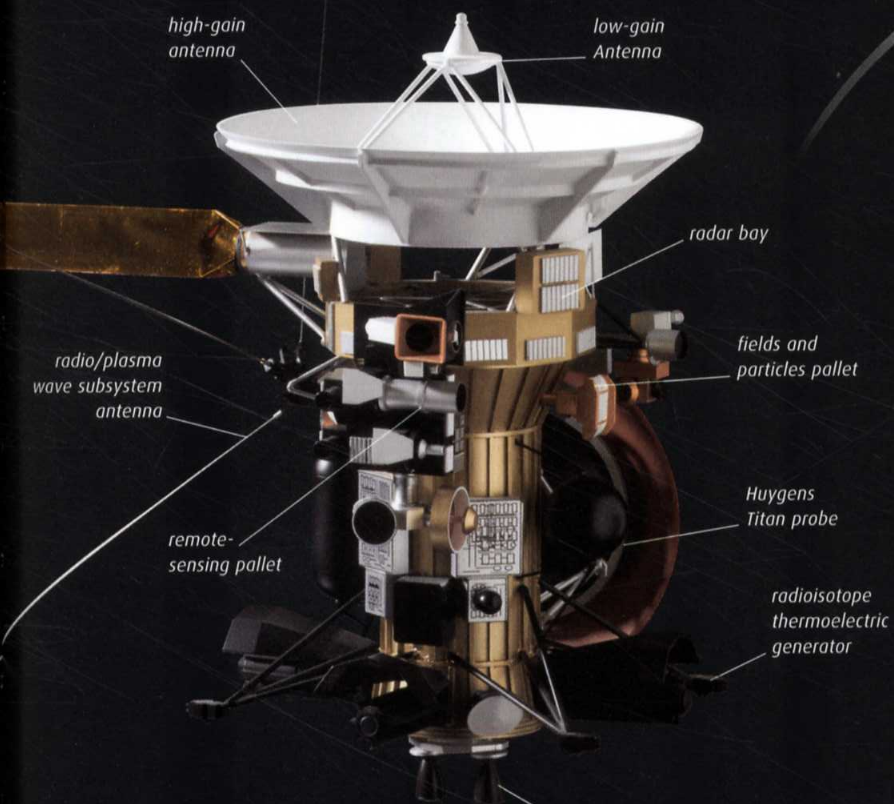
27 October 2004
In a close flyby of Titan, Cassini sends back the first detailed images of the surface beneath the atmospheric haze.

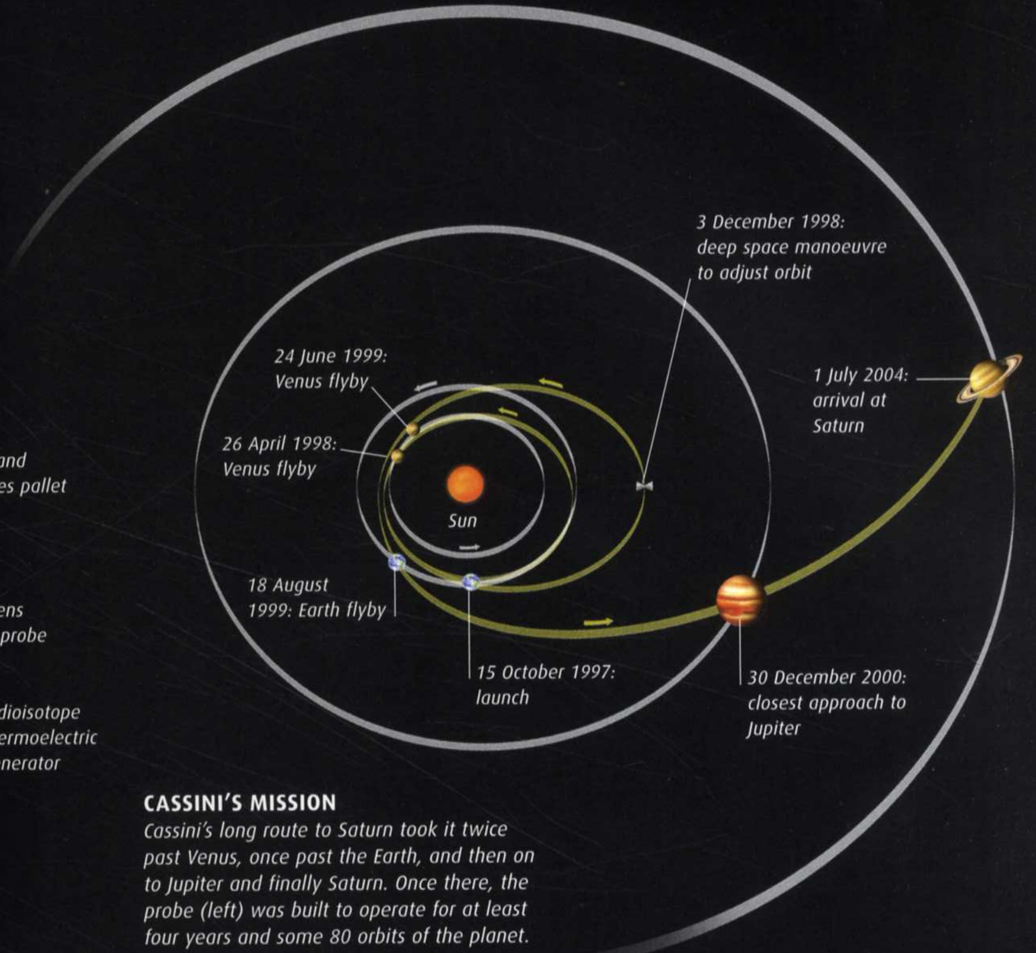
25 December 2004
The Huygens lander separates from Cassini, following its own trajectory towards Titan.

14 January 2005
Huygens enters Titan's atmosphere, sending back pictures and data throughout its descent and landing.

9 March 2005
Cassini flies within 504km (313 miles) of the icy moon Enceladus.

21 July 2006
Using radar imaging, Cassini detects what appear to be lakes on the surface of Titan.





CASSINI'S MISSION
Cassini's long route to Saturn took it twice past Venus, once past the Earth, and then on to Jupiter and finally Saturn. Once there, the probe (left) was built to operate for at least four years and some 80 orbits of the planet.

photographs of the outer moon Phoebe. Now it could begin its work in earnest, with cameras, spectrometers, magnetometers, and a wide variety of other instruments recording every aspect of the planet and its rings and satellites. The lander separated from the main spacecraft on Christmas Day, and Huygens dropped into Titan's atmosphere on 14 January 2005.

The schedule for this phase of the mission had been radically changed when Cassini was already on its way to Saturn. In early 2000, concerned ESA engineers had simulated the way that the lander would relay data via Cassini to Earth. They found a critical flaw – in the original flightplan, the relative motion of the two craft would distort Huygens's signals and make them unintelligible to Cassini. By changing the direction of the vehicles during this critical phase of the mission, disaster was averted.

As Huygens dropped towards Titan, aerial photographs revealed an eerily Earth-like eroded shoreline, and Huygens landed on what seemed to be a pebble-strewn river delta. This confirmed suspicions that Titan is a world where methane (which freezes at -182°C/-296°F) plays a similar role to water on Earth, occurring as ice, liquid, and vapour.

GIANT PROBE
The enormous Cassini dwarfs technicians fitting instruments to it in Kennedy Space Center's Payload Hazardous Servicing Facility prior to launch.

Discoveries in orbit

Although the Titan landing was an early highlight of the mission, Cassini has continued to deliver a wealth of data from its looping flight around Saturn. Its large engine and plentiful propellant have allowed it to make several course corrections, bringing it to within a few hundred kilometres of most of the major moons. One of its most spectacular discoveries was a huge plume of ice crystals erupting from the inner moon Enceladus – a surprising indication that there is liquid water just below its surface.

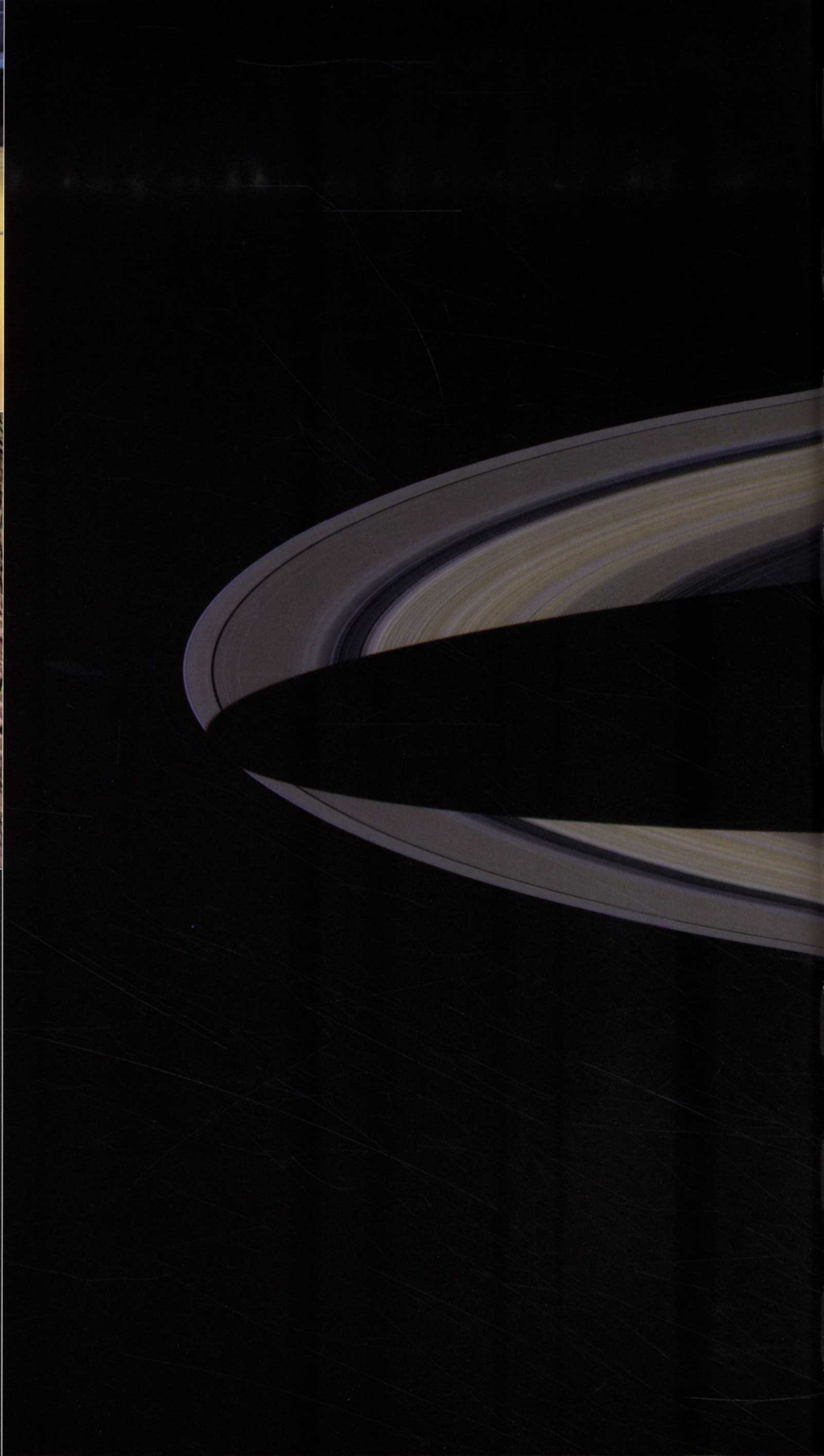
Cassini also went equipped to tackle Titan's hazy atmosphere, with a near-infrared camera that can see through the orange smog and map the terrain below. It has found hot spots, which might be active ice volcanoes on the surface, and reflective patches that are probably lakes of liquid methane. Other moons are less active but seem to have fascinating histories. Dione has towering ice cliffs, Hyperion appears to be the broken-up remnant of a much larger moon, and Iapetus has a dark coating of "soot" on one hemisphere and a bizarre ridge running around much of its equator.

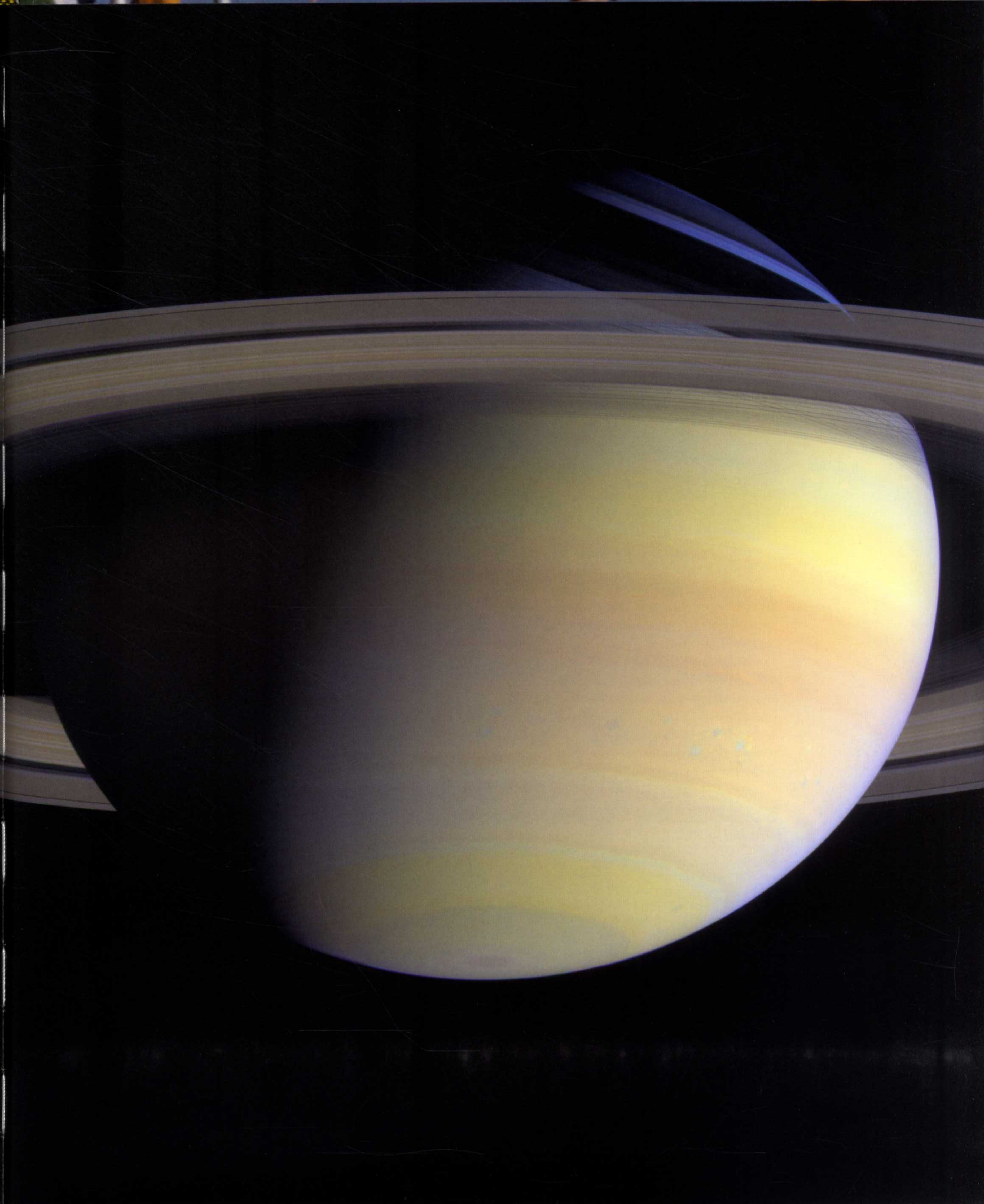
Saturn itself, though outwardly placid, has revealed storms just as violent as those on Jupiter, while its rings seem to be in a constant state of flux and change – composed of billions of individual ice boulders and pebbles, they are twisted and distorted by the gravity of the nearby moons.

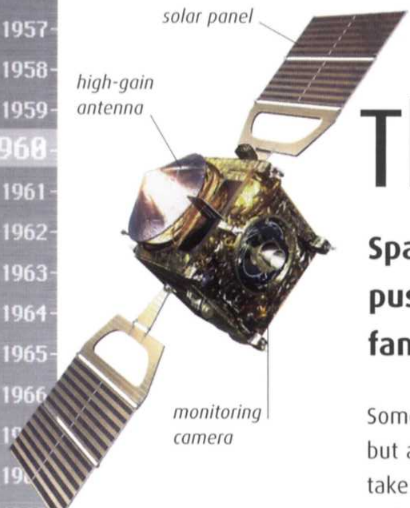
ICY ENCELADUS
A colour-enhanced view of Saturn's inner moon Enceladus shows the coating of fresh "snow" that gives it the brightest surface in the Solar System. The moon's ice plumes erupt along the blue "tiger stripe" features.

CASSINI'S TOUR OF SATURN

All the giant planets have rings around them, but Saturn's are by far the most spectacular – vast, bright planes of orbiting ice chunks, arranged in countless ringlets. Cassini has kept well clear of them after an initial manoeuvre took it through the outer limits of the ringplane in order to get into orbit, but its spectacular images (right) have revealed fine structures and the presence of short-lived twists and knots of material where Saturn's family of moons and moonlets exert their gravitational influence. The moons themselves have also proved impressive – aside from Titan, they are mostly icy, airless worlds. Dione (top) is typical, though its surface is marked by ice cliffs and, like many Saturnian moons, it shows signs that it was not always so deeply frozen. Nevetheless, it makes a beautiful picture against the shadow-striped bulk of Saturn. Enceladus (above) is far from typical, a world with unexpected ice fountains and a cracked surface that suggests water just below.







VENUS EXPRESS
Although it shared a basic design with Rosetta and Mars Express, Venus Express was re-engineered to cope with the hotter conditions close to the Sun.

The next generation

Spaceprobes in the new millennium have continued to innovate and push back the boundaries of our knowledge, whether by transforming familiar worlds or by testing new technologies for the future.

Some ambitious spaceprobes have already left Earth but are following flightpaths that mean they will take many years to reach their destinations. These include the European Rosetta comet probe (see p.273) and NASA's MESSENGER to Mercury and New Horizons mission to the outer Solar System (see p.306). But some other probes are delivering faster results. ESA's Venus Express, launched in November 2005, began its mission around Venus in May 2006. It is the first probe to visit the planet since Magellan in the early 1990s (see p.266) and is based on the same spacecraft design originally devised for the Rosetta mission and successfully adapted for Mars Express. Many of its instruments are also modified spares made as backups for the Mars mission or Rosetta.

Venus Express does not carry an SAR radar like that on Magellan, but it has a wide array of instruments to learn about other aspects of Earth's inhospitable twin. These include a camera for photographing Venusian weather conditions, spectrometers for analyzing the atmospheric chemistry, and a magnetometer for studying the weak magnetic field. Perhaps the most important instrument is VIRTIS, the Visible and Infrared Thermal Imaging Spectrometer – a thermal imager capable of identifying distinct layers in the atmosphere and compiling temperature maps of the surface that could reveal sites of active volcanism.

2 March 2004
ESA's Rosetta comet mission is launched.

3 August 2004
NASA launches MESSENGER, the first Mercury orbiter.

12 August 2005
Mars Reconnaissance Orbiter is launched from Cape Canaveral.

9 November 2005
Venus Express launches on a Soyuz-Fregat rocket from Baikonur.

10 March 2006
Mars Reconnaissance Orbiter arrives in an initial orbit around Mars and begins aerobraking.

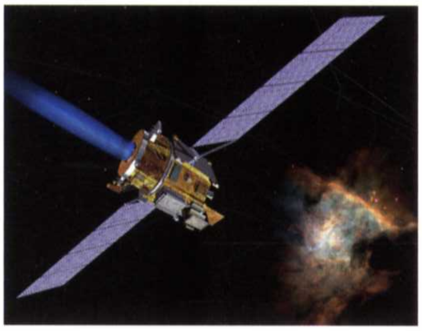
11 April 2006
Venus Express arrives in its initial orbit.

7 May 2006
Venus Express reaches its final working orbit and begins science operations.

3 October 2006
Mars Reconnaissance Orbiter photographs the Mars Exploration Rover Opportunity at the edge of Victoria Crater.

6 November 2006
Mars Reconnaissance Orbiter begins its primary mission.

MARS RECONNAISSANCE ORBITER
NASA's latest Mars orbiter is fitted with cameras to photograph the planet in detail, spectrometers to study the chemical make-up of the rocks, and a radar to look beneath the Martian surface.

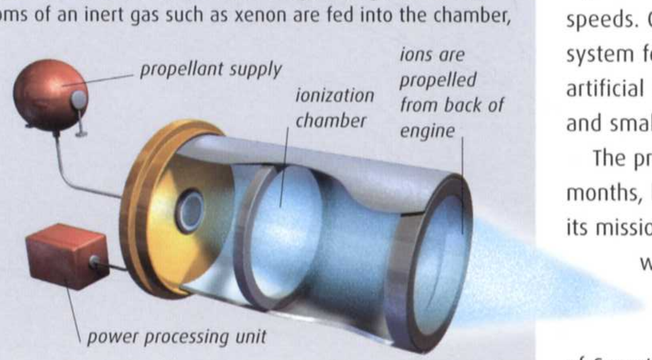


DEEP SPACE 1
An artist's visualization of Deep Space 1 in flight shows the distinct blue exhaust glow that is a hallmark of ion engines.

TECHNOLOGY

THE ION DRIVE

Solar electric propulsion (often known as the ion drive) is a highly efficient alternative to chemical rockets – though unfortunately it is not capable of generating the huge thrusts needed to launch spacecraft out of a strong gravitational field. Electricity from solar panels or another power source is used to create a high voltage across an ionization chamber. When atoms of an inert gas such as xenon are fed into the chamber, they are ionized, breaking apart into electrically charged particles called ions. The xenon ions are repelled by a charged plate in the ionization chamber and pushed out of the back of the engine, generating thrust. Ion engines can propel spacecraft to very high speeds, but run for months not minutes.



A spy above Mars

Meanwhile, 2006 also saw the arrival of NASA's latest Mars probe, the Mars Reconnaissance Orbiter (MRO). As successor to Mars Global Surveyor (MGS), MRO arrived with immaculate timing, entering its final orbit two months before contact with the elderly MGS was lost. The orbiter carries a camera called HiRISE that, at maximum resolution, can take recognizable photographs of objects as small as 1m (3ft) across. MRO's main role will be to take detailed images of craters, canyon walls, and sediment layers, looking for more evidence of water and trying to estimate just when it disappeared from the surface. However, it will also act as an advanced communications relay for current and future surface missions.

Testbed for the future

One of the most influential spaceprobes of all may prove to be a small vehicle launched in 1998. Deep Space 1's primary mission, as part of NASA's New Millennium Program, was to test a variety of advanced technologies, including an ion engine, in space (see panel, left). This efficient engine can generate small amounts of thrust for many months – in this case 0.01kgf (0.3ozf) for 678 days – gradually accelerating a spacecraft to very high speeds. Other tests on Deep Space 1 included a system for concentrating sunlight onto solar cells, artificial intelligence systems for onboard computers, and small, low-mass scientific instruments.

The probe was only supposed to operate for 11 months, but when it showed no sign of deterioration its mission was extended for a further two years, with the ion drive used for changing the spacecraft's orbit to encounter a nearby asteroid. The spectacular finale was a flyby of Comet Borrelly in September 2001.

OPPORTUNITY SNAPPED BY MRO
As well as photographing the Victoria Crater, the Mars Reconnaissance Orbiter's HiRISE camera displayed its amazing resolution powers by capturing the Opportunity Rover, poised near the edge of the crater (inset).

DECEMBER 2019: MOON BOUND
In this artist's impression, NASA's Orion Crew Exploration Vehicle (CEV) waits in orbit as the first astronauts in four decades set foot on the Moon below. If all goes well, the first lunar landing of the new century will come in the 50th anniversary year of Apollo 11.

INTO THE FUTURE

WHEN FUTURE HISTORIANS write the story of mankind's early steps into space from a more distant perspective, 30 October 2000 may be a date of special significance – the last day on which humanity was entirely confined to Earth. The following afternoon, a Soyuz rocket lifted the first crew of the International Space Station into orbit, ready to occupy what should be our first permanent outpost in space. It seems fitting that the station is a collaborative effort between once-hostile nations.

But the ISS is a mere staging post to the Solar System – where next? NASA has lately committed itself to an ambitious project that will see astronauts return to the Moon and establish a semi-permanent base near the south pole, and a younger space power, China, has launched its first manned spacecraft, with longer-term plans that also involve space stations and lunar bases. With these goals fulfilled, it will be time for mankind to look further afield – first to Mars, then deeper into the Solar System, and perhaps, one day, to the stars.

1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

The ISS concept

Conceived in the 1980s as the West's answer to Salyut and Mir, the US space station Freedom eventually evolved into a truly global project – the International Space Station.

25 January 1984
US President Ronald Reagan announces the development of a new US space station to be called Freedom.

23 June 1993
After nine years of planning, constant revisions, and huge budget reductions, Freedom barely survives a Congressional vote on its proposed cancellation.

1 November 1993
NASA announces a partnership with Russia to develop a truly international space station.

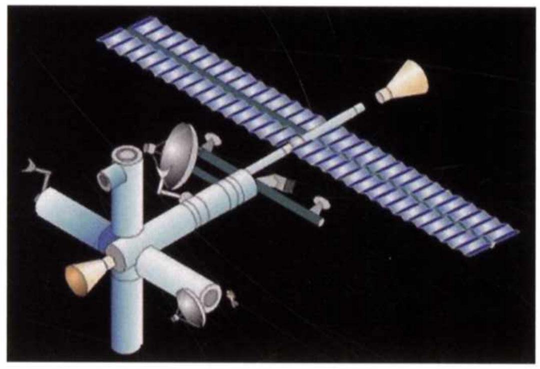
29 June 1995
The Shuttle *Atlantis* docks with the Russian space station Mir, beginning a new phase of cooperation.

20 November 1998
The Russian Zarya Functional Cargo Block, the first element of the ISS, is launched.

7 December 1998
The Space Shuttle *Endeavour* links the US Unity module with Zarya.

26 July 2000
The arrival of the Russian Zvezda module makes the station ready for occupation.

In the early 1970s, budget cuts had forced NASA to choose between the Space Shuttle and a large space station, but in the early 1980s the political winds changed again. Shuttle flights were finally becoming routine, and relations between the superpowers were cooling into a new phase of the Cold War that might again extend into orbit (see panel, opposite). In 1984, President Reagan announced that the United States was at last going to build a permanent space station – with the politically loaded name Freedom.



MIR 2
Authorized in 1976 as an eventual successor to Mir, the Mir 2 design went through many changes until, in response to the US Star Wars project, it threatened to become an orbiting battle platform.

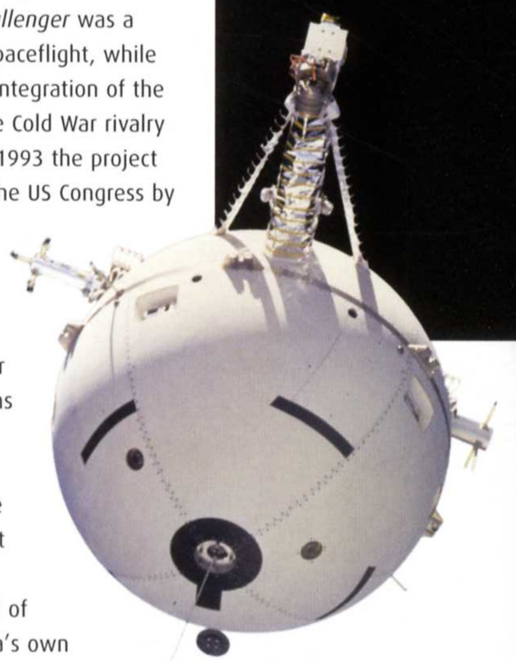
From competition to collaboration

The new station's development was long and tortuous. Initial plans called for a truly huge outpost with a crew of 12, and the European, Japanese, and Canadian space agencies soon joined the project, agreeing to provide their own laboratory modules and other elements. Various designs were proposed, and projected costs spiralled, even as each successive redesign reduced the station's capability. Meanwhile, Shuttle flights carried various experiments to test techniques and technologies that might be used on the station. But the loss of the *Challenger* was a blow to US confidence in human spaceflight, while the liberalization and eventual disintegration of the Soviet Union brought an end to the Cold War rivalry that helped to justify Freedom. In 1993 the project survived a call for cancellation in the US Congress by a single vote.

"We can **follow our dreams** to distant stars, **living and working in space** ..."

US President Ronald Reagan, 25 January 1984

The writing was on the wall for Freedom, but the improved relationship with Russia led to a new way forward. Despite the poor state of their economy, the Russians had space-station experience that could help NASA make its station a reality. In 1993, officials from the US and Russian space agencies met to agree on a joint enterprise: the resulting station would be a hybrid of elements from Freedom and Russia's own stalled Mir 2. At first called Space Station Alpha, before long it became simply the International Space Station (ISS).



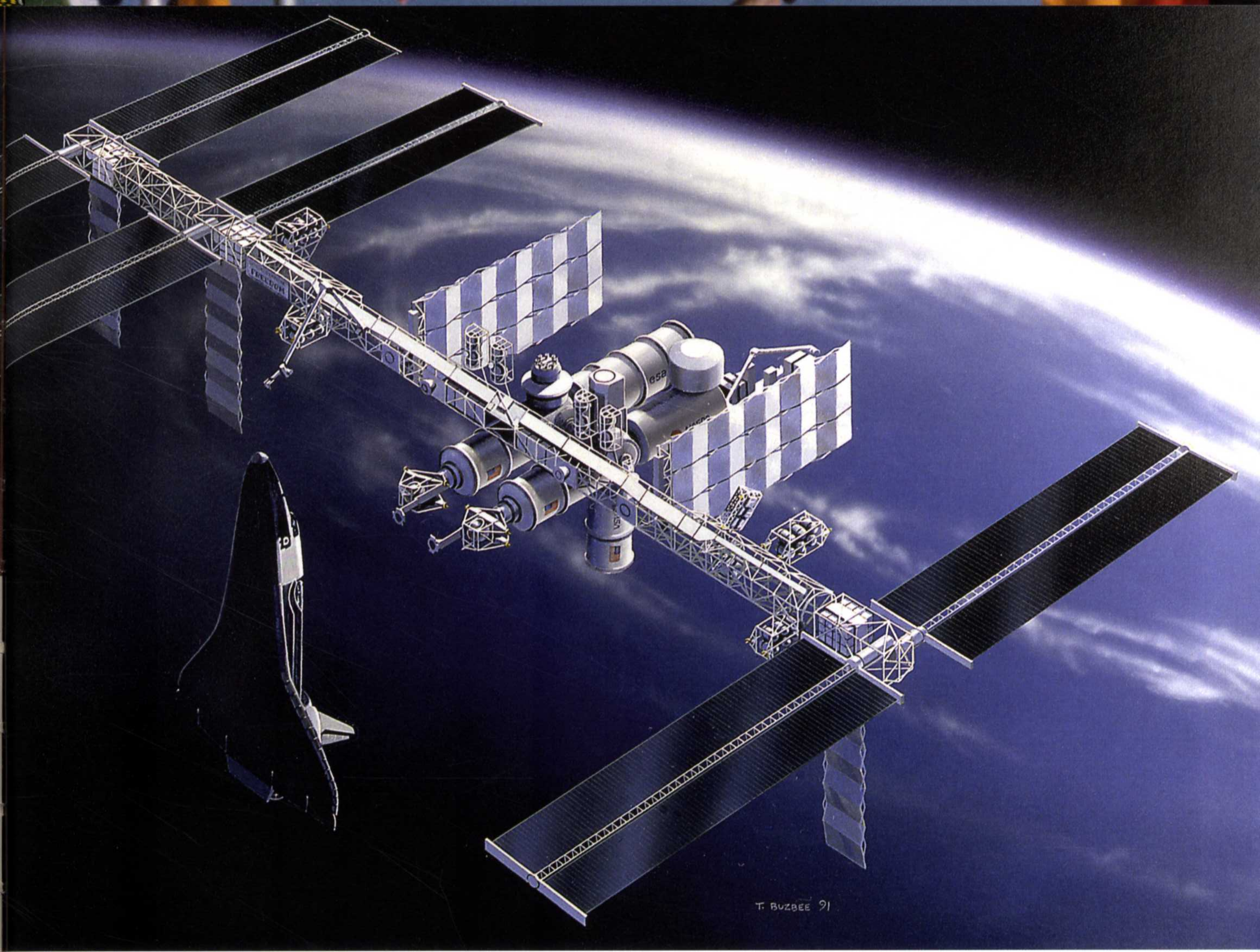
POWER TETHER
In the early 1990s, two Shuttle missions flew an experiment called the Tethered Satellite System (TSS). Linked to the Shuttle by a long conducting wire, its movement through the Earth's magnetic field created electricity. At the time, this technology was considered for use on future space stations.

Construction begins

The new collaborative spirit was tested by the Shuttle–Mir missions of the mid-1990s (see p.216). When these came to an end, it was time to build.

The first element put into orbit was the Russian-built Functional Cargo Block. Known as Zarya, this module had a dual purpose. During the early stages

SPACE TAXI
NASA considered various options for crew transport to the space station – one was the HL-20 lifting body, which got as far as this engineering mock-up.



SPACE STATION FREEDOM
By the early 1990s, constant budget cuts and redesigns had seen the Freedom station evolve into a smaller configuration that bears some resemblance to the ISS. The main similarity is the use of the horizontal truss with solar arrays at each end and pressurized modules in the centre.

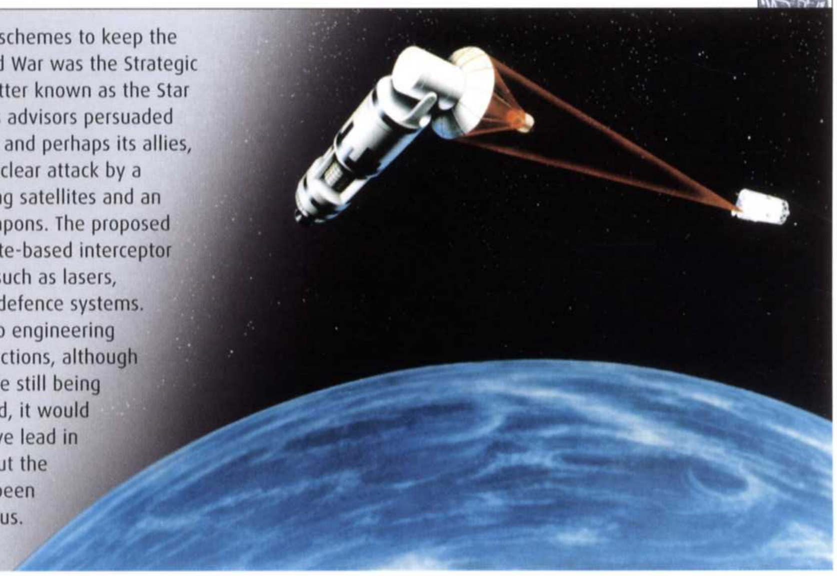
of construction, it would act as the station's heart, generating power and providing propulsion. As the ISS grew larger and these functions moved elsewhere, it would become a storage facility.

Endeavour rendezvoused with Zarya in December 1998, bringing with it NASA's Unity module, the first of three connecting nodes that would join the station's various elements together. However, there was a long delay before the next crucial element, Russia's Zvezda service module arrived. This provided living accommodation, life support, and environmental controls. Once it had docked in July 2000, the ISS was at last ready for its first crew.

TECHNOLOGY

STAR WARS

One of President Reagan's schemes to keep the upper hand in the new Cold War was the Strategic Defense Initiative (SDI), better known as the Star Wars programme. Reagan's advisors persuaded him that the United States, and perhaps its allies, could be protected from nuclear attack by a network of missile-detecting satellites and an array of science-fiction weapons. The proposed SDI arsenal included satellite-based interceptor missiles, energy weapons such as lasers, and ground-based missile-defence systems. Development stalled due to engineering problems and budget restrictions, although some of its technologies are still being pursued. Had SDI succeeded, it would have given the US a decisive lead in the Cold War arms race – but the effects of that could have been unpredictable and dangerous.

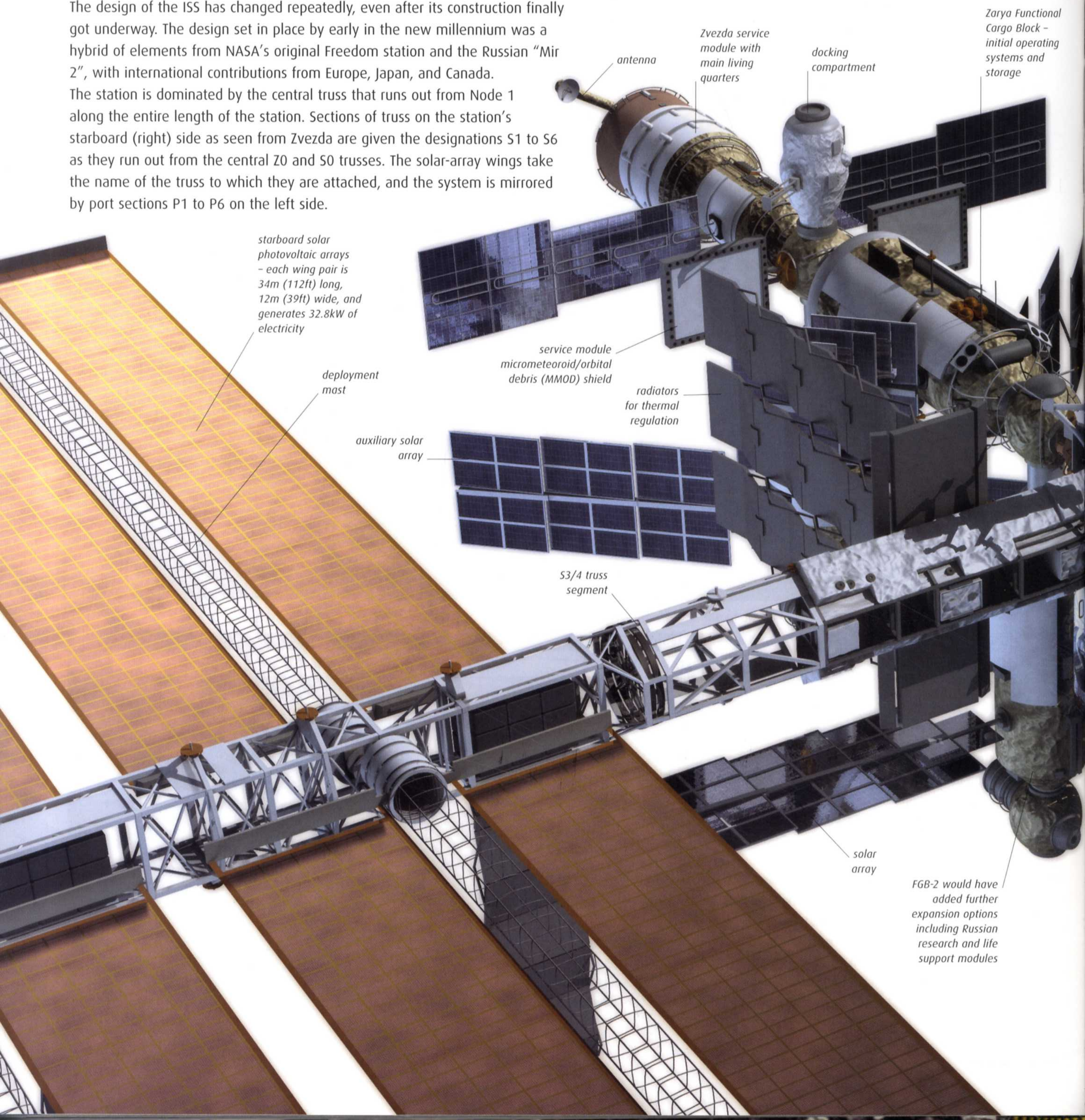


TECHNOLOGY

A PERMANENT OUTPOST IN SPACE

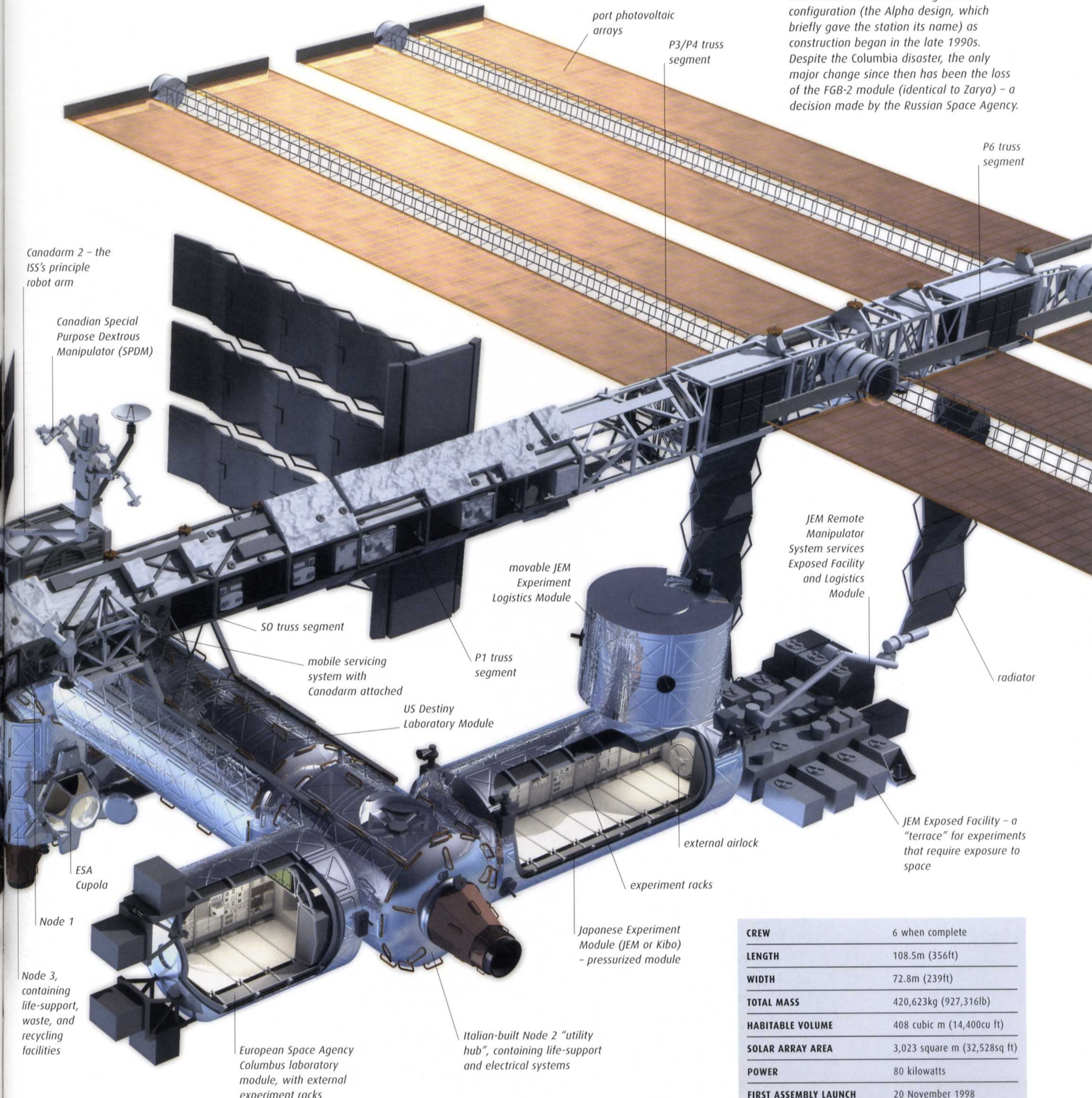
The International Space Station

The design of the ISS has changed repeatedly, even after its construction finally got underway. The design set in place by early in the new millennium was a hybrid of elements from NASA's original Freedom station and the Russian "Mir 2", with international contributions from Europe, Japan, and Canada. The station is dominated by the central truss that runs out from Node 1 along the entire length of the station. Sections of truss on the station's starboard (right) side as seen from Zvezda are given the designations S1 to S6 as they run out from the central Z0 and S0 trusses. The solar-array wings take the name of the truss to which they are attached, and the system is mirrored by port sections P1 to P6 on the left side.

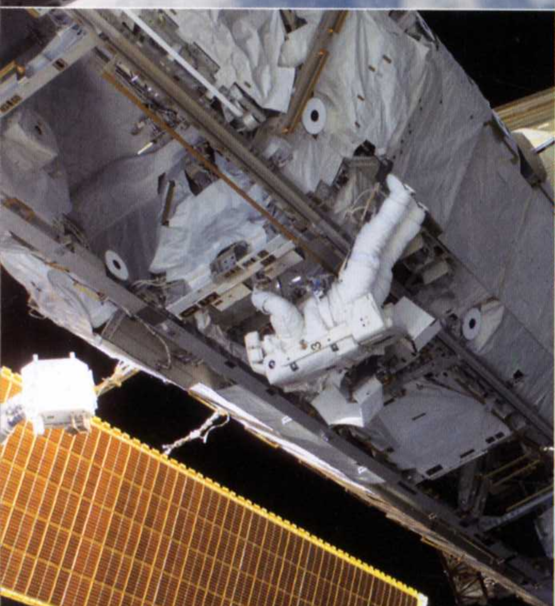


THE ISS VISION

This illustration shows the agreed ISS configuration (the Alpha design, which briefly gave the station its name) as construction began in the late 1990s. Despite the Columbia disaster, the only major change since then has been the loss of the FGB-2 module (identical to Zarya) – a decision made by the Russian Space Agency.



CREW	6 when complete
LENGTH	108.5m (356ft)
WIDTH	72.8m (239ft)
TOTAL MASS	420,623kg (927,316lb)
HABITABLE VOLUME	408 cubic m (14,400cu ft)
SOLAR ARRAY AREA	3,023 square m (32,528sq ft)
POWER	80 kilowatts
FIRST ASSEMBLY LAUNCH	20 November 1998
FINAL CONSTRUCTION LAUNCH	2010 (scheduled)



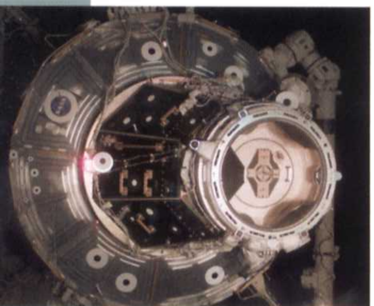
POWER IN SPACE
(Top) In order to regulate power to the ISS, the solar arrays must be able to swivel and face the Sun at all times. During Atlantis's STS-115 mission in September 2006, a spacewalk by Daniel Burbank (pictured) and Steve MacLean prepared the Solar Array Rotary Joint mechanism for operation.

UNDER CONSTRUCTION
(Above) The chief purpose of STS-115 was to install the P3/P4 section of the station's main truss, along with its solar arrays. Here astronaut Heidemarie M. Stefanyshyn-Piper works on the underside of the truss during the third and final spacewalk of the flight.

USING CANADARM
(Right) Burbank and MacLean hitch a ride on the Mobile Base System that allows the ISS's Canadian-built robot arm to move along the central trusses. An updated version of the RMAs used on the Shuttle, the Canadarm can be operated from inside the Destiny laboratory or by a spacewalking astronaut.

ISS expeditions

Since the first crew arrived in October 2000, the International Space Station has been continuously manned. As well as ongoing construction, the astronauts aboard work on a wide variety of scientific experiments.



FINAL APPROACH
The docking adapter on the US Destiny laboratory looms large in this photograph taken from Endeavour *seconds before it docked with the ISS in June 2002, bringing a new station crew to relieve Expedition 4.*

2 November 2000
The first crew of the International Space Station arrives aboard Soyuz TM-31.

10 March 2001
The crew of Expedition 2 arrives aboard the Space Shuttle *Discovery*. The station's first handover is accomplished.

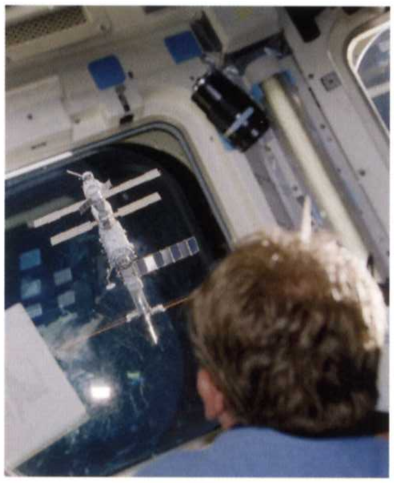
30 April 2001
The ISS welcomes Dennis Tito, the first of several space tourists on visiting Soyuz missions.

8 October 2001
The first spacewalk by ISS astronauts takes place to attach the Russian Pirs docking module.

26 April 2003
Following the loss of *Columbia*, Soyuz TMA-2 brings the Expedition 7 crew to the ISS, and the station is temporarily reduced to two crew members.

6 July 2006
The return of *Discovery* to the ISS brings a resumption of three-person crews. The new crew member, German Thomas Reiter, is also ESA's first ISS astronaut.

Long-duration stays aboard the ISS are known as expeditions. Each typically lasts around six months, during which the station's crew will often welcome visitors on either the Space Shuttle or the Russian Soyuz spacecraft. While the station is largely incomplete, each expedition is limited to three people (scaled back to just two following the *Columbia* disaster – see p.297). But as more space becomes available, the crew will rise to six.



FIRST HANDOVER
Shuttle astronaut Andrew Thomas enjoys the view of ISS from Discovery *during its approach to the station in March 2001. This STS-102 mission saw the handover between the crews of Expeditions 1 and 2.*

Early expeditions

The first expedition set a pattern for other early crews. The commander was NASA astronaut William Shepherd, while the other two crew members were Russian – Sergei Krikalev (see p.297) and Yuri Gidzenko. Arriving on Soyuz TM-31, they spent most of their four-month flight getting the ISS fully operational and carrying out assembly tasks (see over). In February 2001, they welcomed the crew of *Atlantis* and the US Destiny laboratory module. March saw *Discovery* arrive, bringing with it the Expedition 2 crew of Yuri Usachev, Susan Helms, and James Voss (one cosmonaut and two astronauts). As well as construction work, they carried out experiments on how to protect spacefarers from radiation. In April, they were joined by the crew of Soyuz TM-32, including Dennis Tito, the first space tourist (see p.308). In August, a new crew arrived from *Discovery* and spent four-months concentrating largely on science. Expeditions 4 and 5 increased the station's scientific workload during their six-month missions (December 2001–June 2002 and June–November 2002), doubling the number of experiments carried onboard and receiving some of the first scientific payloads from private companies. The launch of the Expedition 6 crew saw the debut of a new class of Soyuz spacecraft, the Soyuz TMA, upgraded largely to accommodate taller passengers.

Throughout this period, the station continued to grow, with the addition of airlock modules, the first elements of the station's main truss, and the station's main robot arm, Canadarm2.

Back to basics

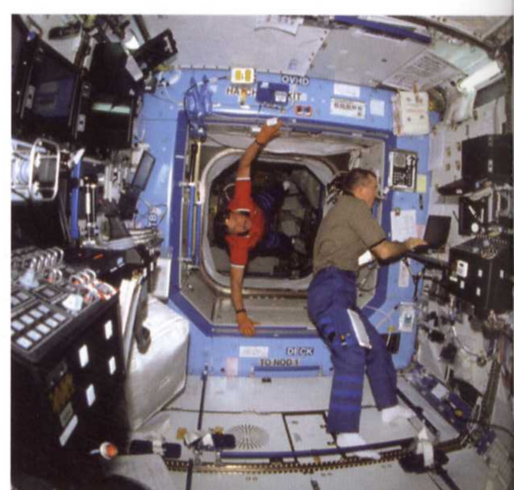
The period of expansion came to an abrupt halt two months into Expedition 6, as the loss of *Columbia* deprived the station of its main supply vehicle and construction tool (see p.296). With the station cut back to a crew of two and forced to rely on smaller Russian spacecraft alone, Expeditions 7 to 11 were dominated by the need to keep the ISS operational in its half-finished state – science temporarily had to take second place to routine maintenance and repair. The Space Shuttle finally returned to the ISS with *Discovery*'s STS-114 "return to flight" mission in late July 2005, delivering supplies halfway through Sergei Krikalev and John

BIOGRAPHY

MICHAEL FOALE

British-born Michael Foale (b.1957) is one of NASA's most experienced space-station astronauts, having spent time on Mir in 1997 as well as commanding Expedition 8 to the ISS. After studying physics and astrophysics in the UK, Foale moved to Houston, joining the staff at Johnson Space Center in 1983. He was selected for astronaut training in 1987 and has also flown on Space Shuttle missions STS-63 (*Discovery*'s "near Mir" mission) and STS-103 (replacing the HST's steering gyroscopes).

MIR LIVES ON
A view into the Zvezda Service Module on the ISS shows the stations's main crew quarters. Zvezda began life as the core of the Mir 2 station and follows a design that dates back to the Salyuts.



DESTINY LABORATORY
Astronaut James Voss of Expedition 2 works in the US laboratory module, as visiting astronaut Scott Horowitz floats through the hatchway from the Unity module.

HOUSE PLANTS
Some experiments are welcome outside the laboratory modules – plant propagators are a good example. Here, visiting Belgian astronaut Frank De Winne tends to a plant-growth experiment in the living quarters of the Zvezda Service Module.

Phillips's Expedition 11. However, this proved to be a false dawn, as continuing problems with the Shuttle led to another year-long grounding, and the crew of Expedition 12 also found themselves reliant on Russian Soyuz and Progress spacecraft.

A growing crew

Discovery's successful second "return to flight", in July 2006, brought normality back to the ISS. German astronaut Thomas Reiter arrived on *Discovery*, joining Pavel Vinogradov and Jeffrey Williams (who had arrived on Soyuz TMA-8 three months previously) to bring the crew for Expedition 13 back up to three. Reiter, Europe's first ISS Expedition member, remained aboard after the handover to Expedition 14 in September: new Commander Michael Lopez-Alegria arrived with Mikhail Tyurin on a Soyuz and spent three months with Reiter before *Discovery* brought Sunita Williams to take his place.

Expeditions 15 and 16, coinciding with the 50th anniversary of the Space Age, see this more complex staggered schedule continue, as Shuttle construction missions interweave with Soyuz launches to ferry new crew members to and from the station. As more laboratory space becomes available, and the ISS crew eventually increases, the station's scientific work will finally dominate over the time spent on its construction and maintenance.

IN THE QUEST AIRLOCK
(Right) The Quest Joint Airlock arrived on Atlantis *in July 2001 and is a doorway to space for crew members in both Russian and US spacesuits. Expedition 4's Daniel Bursch (left) and Carl Walz are shown testing the airlock.*

TECHNOLOGY

CRYSTALS IN SPACE

Some of the ISS's hardest-working pieces of equipment are the crystal growth experiments. Crystal growth in the microgravity conditions of orbit has become an important area of space-station science, since without the effects of gravity, crystals form quickly and with few imperfections. The kinds of crystals grown on the ISS vary from proteins to minerals, and are usually returned to Earth for research and analysis. Although large-scale orbital factories are not yet a reality, the ability to study "perfect" crystals can help to improve manufacturing methods here on Earth.

ORBITING EDUCATORS
Ed Lu of Expedition 7 presented a series of Saturday Morning Science *shows from the ISS that were shown back on Earth, demonstrating the effects of microgravity in the US Destiny laboratory.*

EXPERIENCE

MANNING THE ISS

Expedition to "Alpha"

OFFICIAL PORTRAIT
William M. Shepherd, first commander of the International Space Station, and his crewmates Sergei Krikalev (left) and Yuri Gidzenko (right) pose in their Sokol spacesuits prior to launch.

The first crew of the International Space Station had an arduous list of duties, firstly getting the linked Zarya, Zvezda, and Unity modules fully operational, and then preparing the station for scientific work.

Launched from Baikonur aboard Soyuz TM-31 on 31 October 2000, Shepherd, Krikalev and Gidzenko docked with the station on 2 November. A Shuttle mission had visited in the previous month and installed a variety of external fittings, including communications antennae and the Z1 truss. Life-support systems had also been activated, so the crew were able to open the hatch from their Soyuz, enter the station, and get straight to work. Expedition commander Shepherd, a naval man by training, was bothered by the ISS's lack of a name, so he requested during the first radio conversation that, at least for this mission, it should revert to its 1990s name of Alpha. NASA administrator Daniel Goldin acquiesced, to applause in Mission Control.

"I think the **air quality** has been very good. I am surprised at the amount of air that gets moved through filters up here – it is pretty substantial. Anything we have that gets loose – food, things like that – they are in a filter in matter of **a minute or two** – it is pretty surprising. Odours? Non-existent. I am very surprised at how well all the **environmental equipment** has been working so far."

William Shepherd, interviewed by CNN, 18 December 2000

ERUPTION FROM SPACE
When the Mexican volcano Popocatapetl began to belch smoke in late-January 2001, the Expedition One crew managed to snap this stunning photo as the space station's orbit carried them northeast of the mountain.

AT WORK IN ORBIT
After launch from Baikonur on a Soyuz rocket, the Expedition One crew settled in and began to get the ISS systems up and running. Communications were an early priority – the crew had to rely initially on Russian communications equipment, with corded headphones that restricted movement. By the time Atlantis arrived with the Destiny module in February 2001, things were starting to feel more homely.

RELIEVED
This scene of Discovery*'s tail section against clouds on Earth was photographed from aboard the station after STS-102 had docked in March 2001, bringing with it a new crew for the ISS.*

"We opened the hatches ... and it was very pleasant to find ourselves in a place ... with good, clean air."

Sergei Krikalev, 2 November 2000

For the first month, the crew were restricted to the two Russian modules – they did not have sufficient power to run the Unity module, and so it remained sealed up until *Endeavour* arrived in December, bringing with it the first of the huge solar arrays. However, there was plenty to do unpacking the large amounts of equipment, ranging from clothes to laptop computers, left behind by visiting Shuttle missions prior to their arrival – and more arrived on two Progress ferries during the expedition. Unity contained a similar stash of equipment when finally opened, and by the time this was all installed, the next Shuttle mission was approaching. The main aim of *Atlantis*'s STS-98 mission in mid-February 2001 was to install the US Destiny module. There was plenty to do setting up the new laboratory, although it arrived without experiments aboard – the first of these arrived with *Discovery* on 10 March 2001. But that Shuttle also brought a new crew, and it would be their job to begin the station's scientific programme.

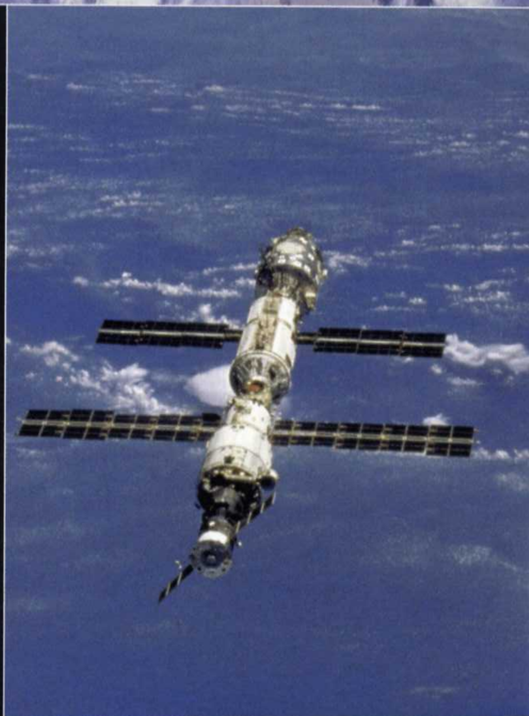
"... from all the people on the ground here in Houston and in Moscow and around the world [who] have supported you through this flight, it has been an **honor and privilege**, and you have our sincere thanks for your **outstanding duty** on Alpha. Your accomplishments are impressive. We witness your departure with both regret and happiness: regret because we will miss working with you; happiness because you are speeding home towards a reunion with family and friends and a **well-deserved rest.**"

Cady Coleman, Capcom, 18 March 2001

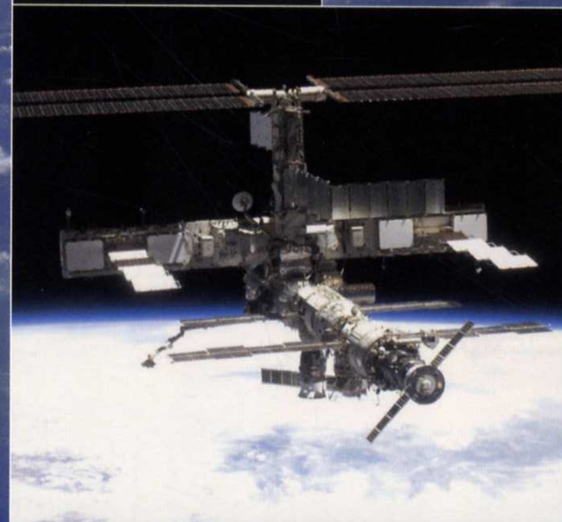
RETURN CEREMONY
(Left to right) Krikalev, Shepherd, and Gidzenko are feted upon their return to Earth at a reception at the Ellington Field Air Force Base near Houston.

1998–2000
(Above) The initial building blocks of the ISS, Unity and Zarya, remained docked in orbit for 18 months awaiting the next stage of construction.

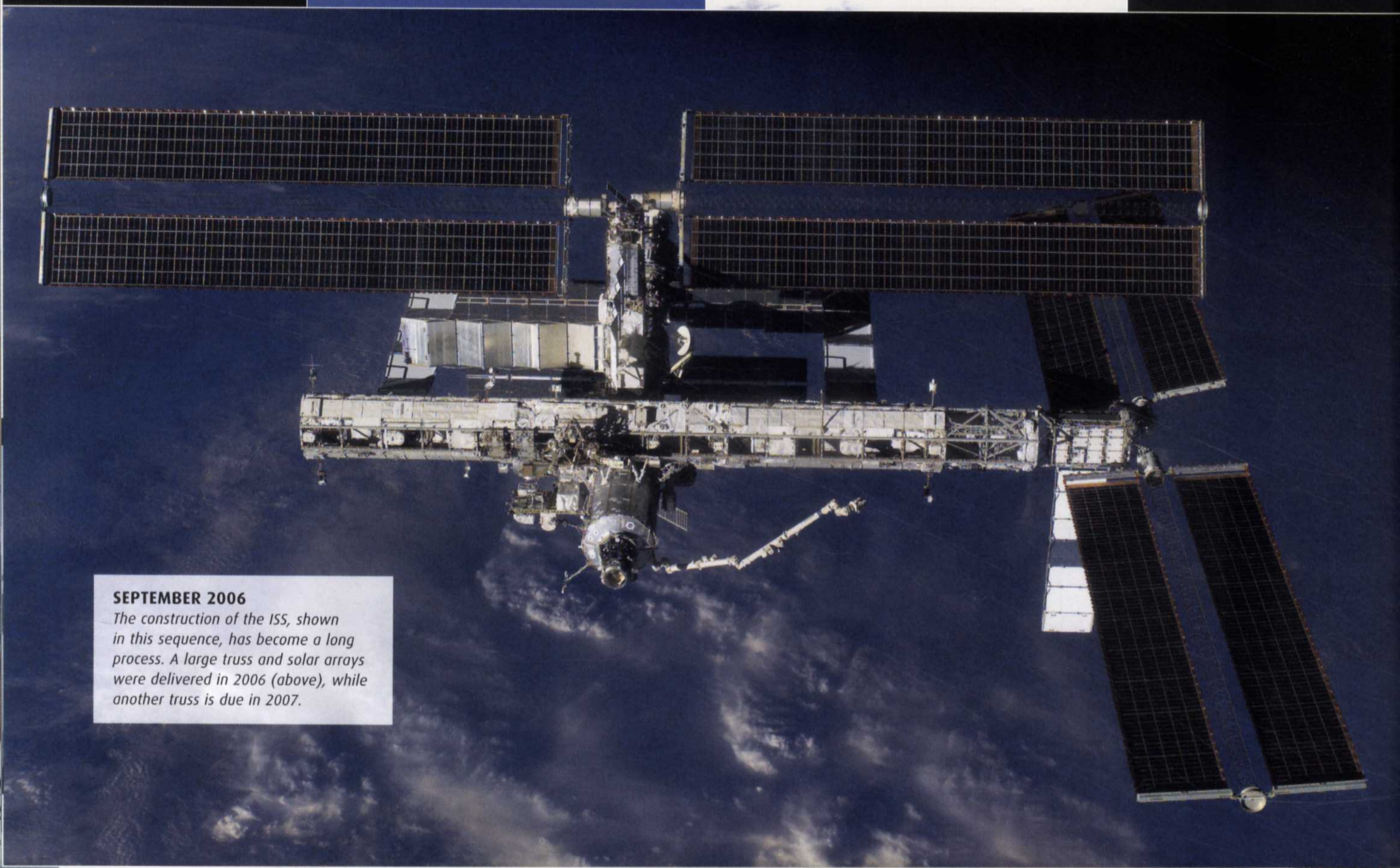
SPRING 2001
(Right) A burst of construction work began in late 2000 and saw the addition of the Z1 truss (a temporary mounting point for the P6 truss and the first large solar array) as well as the Destiny laboratory and the Canadarm2 remote manipulator.



AUTUMN 2000
(Right) With the addition of the long-delayed Zvezda service module, the station was finally ready for occupation by the crew of Expedition 1.



AUGUST 2005
(Left) For three years, the station remained in limbo. When Shuttle flights were cancelled in the wake of the Columbia disaster, the first sections of the main truss had been added, as well as new airlock compartments and solar arrays.



SEPTEMBER 2006
The construction of the ISS, shown in this sequence, has become a long process. A large truss and solar arrays were delivered in 2006 (above), while another truss is due in 2007.

Completing the station

The loss of *Columbia* in 2003 threw the construction of the ISS into chaos and its entire future into doubt. But eventually the collaborating space agencies agreed a new schedule to complete the station.

In the immediate aftermath of the *Columbia* disaster, the fate of the ISS was a pressing issue. The crew of Expedition 6, in orbit since November 2002, were supposed to be replaced during a visit from *Atlantis* in March 2003, but it was clear that the Shuttle would be grounded for a long time. There was some discussion of abandoning the station until the Shuttle flew again, but Russia stepped into the breach, suggesting that the Soyuz TM should take over the Shuttle's taxi role. However, the difficulty of keeping the station fully supplied using only Progress M ferries meant that the station's crew would be temporarily reduced to just two. This had the effect of reducing the amount of science that could be conducted onboard and increased the grumbling of those who saw the ISS as an expensive drain on the budget for Earth-based research. Only with the Shuttle's return to the ISS in July 2006 did the three-person expeditions resume.

BACK TO THE ISS
Shuttle astronaut Joseph R. Tanner climbs along the ISS truss during installation of a new truss segment and solar arrays in September 2006.

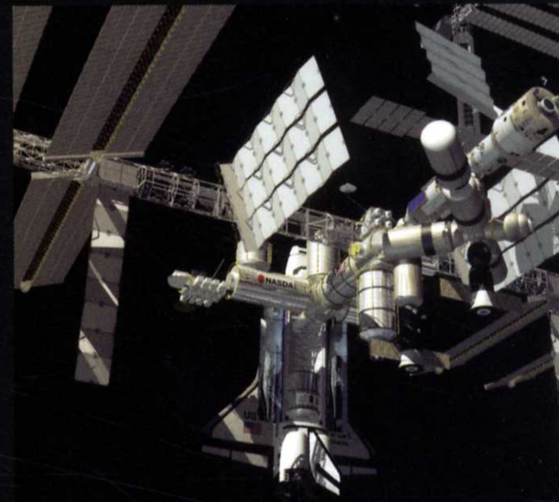
Finding a way

The loss of *Columbia* finally led to a recognition of inherent dangers in the Shuttle's design, and in 2004 President George W. Bush outlined a new space policy for the future of NASA (see p.302). With the eventual loss of another Shuttle now seen as almost inevitable, the vehicle would be retired as soon as possible, and stringent safety precautions would be in place throughout its remaining missions. The challenge now was to complete the ISS in as few missions as possible, but after some haggling between the various agencies, a revised launch schedule calling for 17 more Shuttle flights was agreed in March 2006.

While several of the remaining Shuttle missions will involve the transportation and fitting of truss segments and solar arrays, there are also important pressurized modules to be added. Nodes 2 and 3, ESA's Columbus laboratory module, and the Cupola observation port all require Shuttle launches (though the Cupola and Node 3 should be launched together on the penultimate Shuttle flight), while Japan's JEM laboratory requires three launches to put all its components into orbit. In addition, at least one Russian laboratory module will be added, though this will be launched by a Proton rocket.

Life after the Shuttle

By the time the Shuttle departs for the last time, around 2010, the ISS should at last be fully operational, with a permanent crew of six onboard. A variety of vehicles, both new and familiar, will fulfil the Shuttle's various roles. At least two Soyuz spacecraft will stay permanently docked for use as lifeboats, while others come and go bringing visitors and replacement crews. Russian Progress ferries, ESA's Automated Transfer Vehicle, and Japan's H-II Transfer Vehicle will carry supplies and experiments to and from the station. By the mid-2010s, these spacecraft will be supplemented with visits from NASA's new Orion spacecraft, and perhaps others – proposals include a new Russian spaceplane, a European vehicle based on Soyuz, and even spacecraft developed by NASA specifically for commercial launches.



THE PLANNED STATION
An artist's impression shows a Shuttle docked to the completed station. With the Space Shuttle due to go out of service as soon as the ISS is completed, this configuration may only be seen once, during the final mission of Discovery *– currently scheduled for April 2010.*

BIOGRAPHY

SERGEI KRIKALEV

A talented pilot and engineer, Sergei Konstantinovich Krikalev (b.1958) joined NPO Energia (the former OKB-1) in 1981. At first he worked on engineering problems such as the Salyut 7 rescue mission (see p.182), but in 1985 he was selected for cosmonaut training. Assigned to his first Mir mission in 1988, he flew on Soyuz TM-7 and remained in orbit for 151 days. He flew again on Soyuz TM-12 in May 1991 and was in orbit when the Soviet Union ceased to exist in December, eventually returning to Earth after ten months. In the 1990s he flew on the STS-60 and STS-88 Space Shuttle missions, before serving on the crew of ISS Expedition 1. His command of Expedition 11, during which station construction resumed, brought his total time in space to a record 804 days.

14 January 2004
President George W. Bush announces the Vision for Space Exploration, effectively signalling the end of the Space Shuttle programme.

July 2005
Unexpected problems during *Discovery*'s first return to flight mission leave the Shuttle grounded for another year. However, *Discovery* does manage to deliver supplies to the station.

2 March 2006
Heads of the US, Russian, European, Canadian, and Japanese space agencies meet at Kennedy Space Center to approve a new assembly sequence that will see the ISS completed within four years.

July 2006
Discovery's second return to flight mission delivers more supplies and components to the station and brings the crew back up to three.

September 2006
Atlantis docks with the ISS, bringing with it a major new section of the truss and solar arrays.

December 2006
Discovery adds further truss components and brings a new crewmember to the station.

1955 1956 1957 1958 1959 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

4 February 1986
During his State of the Union address, President Reagan proposes a hypersonic "Orient Express" aerospaceplane called the NASP.

5 February 1986
The British government announces development of HOTOL.

25 July 1988
HOTOL is scrapped when the UK government withdraws funding.

May 1993
The NASP project is cancelled.

18 August 1993
The DC-X Delta Clipper SSTO vehicle makes its first test flight.

31 July 1996
A fire on the launch pad destroys the DC-X prototype. NASA decides not to rebuild and cancels the project.

November 1999
A prototype fuel tank for the X-33 fails during testing, leading NASA to cancel the project due to concerns about its viability.

13 November 2006
Blue Origin's prototype SSTO vehicle makes its first short flight.

Successors to the Shuttle

Despite the Space Shuttle's checkered history and imminent retirement, the concept of the spaceplane has too many benefits to disappear completely. So what will the next generation of spacecraft look like?

Even before the Shuttle first flew, a range of ideas were circulating about what might ultimately replace it. The Shuttle design is far from economical, since it is only partially reusable: the key to cheap spaceflight lies in simple, fully reusable vehicles that can launch, return to Earth intact, and be ready for another flight after minimal servicing. Countless solutions to this challenge have been proposed, but the history of spaceflight is littered with their remains.

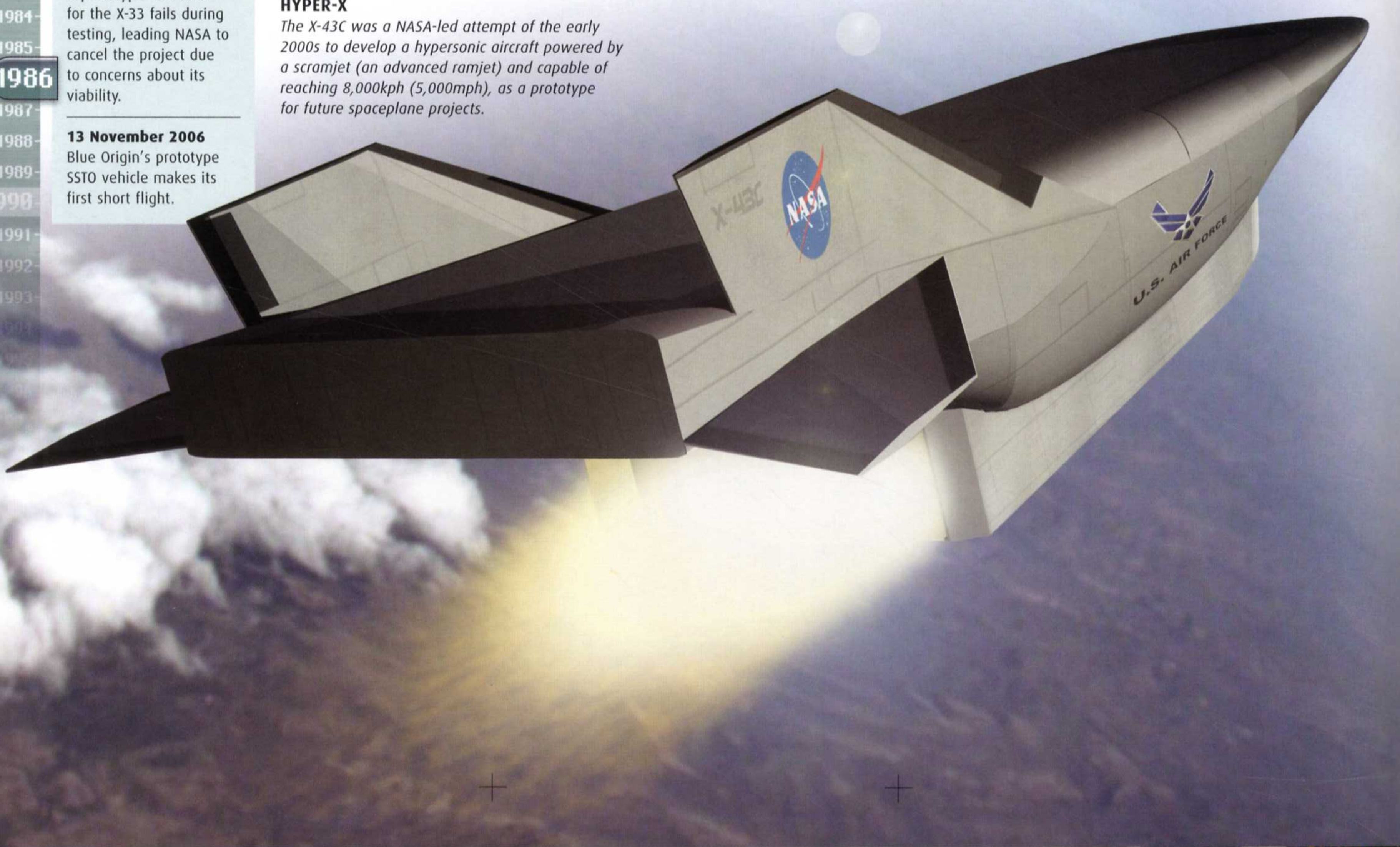
SANGER'S AMERIKA
Eugen Sanger's Second World War design for a rail-launched German orbital bomber, called Amerika, is still an inspiration for many aerospaceplane concepts today.

Next-generation spaceplanes

One of the most popular routes has been the Shuttle-like, full-sized spaceplane, sometimes reduced to a single stage or stacked in a reusable design similar to the British MUSTARD (see p.188). The very first spaceplanes, envisioned by Austrian engineer Eugen Sanger in the 1930s, were rocket-powered aircraft launched horizontally on a rail track, accelerated to high speed before takeoff by a rocket-propelled shunt that remained on the ground.

Several possible designs for the Space Shuttle used carrier aircraft that would fly to the edge of space and then release a smaller spacecraft to continue into orbit. They were rejected due to the impractical size of the carrier craft, but the concept, used by the Bell X1 (see p.34) and the X-15 (see p.188), has been revisited and proven again by the privately developed SpaceShipOne (see p.309).

An alternative is the hybrid aerospaceplane – a spacecraft that behaves like a normal aircraft in the atmosphere, accelerating to hypersonic speeds before transforming into a rocket at high altitudes.



HYPER-X
The X-43C was a NASA-led attempt of the early 2000s to develop a hypersonic aircraft powered by a scramjet (an advanced ramjet) and capable of reaching 8,000kph (5,000mph), as a prototype for future spaceplane projects.

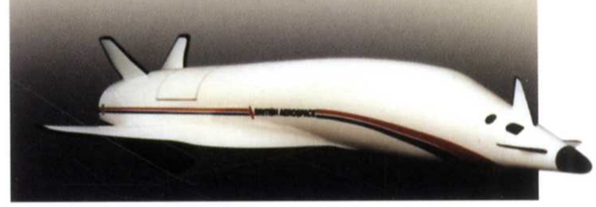
SPACE STATION LIFEBOAT
The X-38 was a prototype of a lifting body Crew Return Vehicle intended for use on the ISS. It passed a number of drop tests from a NASA B-52 before its cancellation in 2002.

MILITARY TAKEOVER
The X-37 experimental launch vehicle was first developed by NASA as a potential Shuttle successor, but has since been taken over by the DARPA defence agency. A new version is intended to launch on an Atlas rocket in 2008.

HISTORY FOCUS

THE HOTOL SPACEPLANE

The HOTOL (Horizontal Take-Off and Landing) spaceplane was a British project of the late 1980s that was among the first to use an air-breathing rocket engine. This would have drastically reduced the amount of liquid oxygen needed to combust with HOTOL's liquid hydrogen fuel. Along with a rocket-assisted launch sled for an initial speed boost, it would have allowed the spacecraft to reach low Earth orbit with a 7,000kg (15,500lb) payload, gliding back to Earth at the end of its mission. The project stalled in 1988, a victim of repeated modifications as the designers tried to compensate for the massive weight of the engine and the payload capability became too small for viability. An attempt to develop a modified version, to be launched from a Russian An-255 transport aircraft, was abandoned in the early 1990s.



When the concept was first suggested in the 1980s, in forms such as the British HOTOL and the US National Aerospace Plane (NASP), the technology required to make such vehicles a reality was still in its early stages of development. Now that ramjets have matured (see panel, below), the idea is being revisited in earnest.

Mini-shuttles

A variety of proposals for small, Shuttle-like spacecraft have come and gone over the years. However, most of these transport craft would use the spaceplane concept only for atmospheric re-entry – they would be launched in a more conventional way, mounted on top of a rocket. This gives them more than a passing resemblance to the US Air Force's Dyna-Soar project of the 1960s. Examples of such "mini-shuttles" include ESA's Hermés project (see p.231), Japan's similar HOPE (H-II Orbiting Plane), and a proposed Crew Return Vehicle for the International Space Station. Russian space contractor Energia is currently developing a similar spacecraft called Kliper, which might fly as early as 2012.

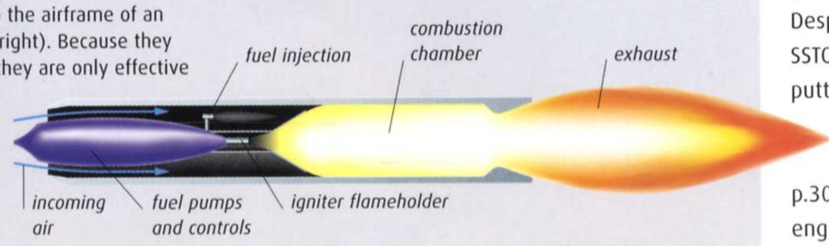
Single stage to orbit

Another radical approach to the problem of reusable launch vehicles is to integrate spacecraft and rocket so that the entire vehicle travels into space and returns to Earth intact. This single-stage-to-orbit (SSTO) concept was developed and tested by the McDonnell-Douglas Delta Clipper or DC-X, as part of the SDI "Star Wars" project (see p.287). DC-X made short flights several times during the early 1990s (the prototype was not intended to reach space) and was taken on by NASA after the SDI budget was slashed. However, NASA already had a competing project, the X-33, in development, and when DC-X caught fire during a test in 1996, the project was abandoned (X-33 followed it into oblivion a few years later). Despite NASA's loss of interest in the project, the SSTO concept is sound, and the potential savings on putting payloads into orbit are impressive. Recently, the private sector has risen to the challenge, and Jeff Bezos's Blue Origin project (see p.309), whose staff includes several former DC-X engineers, has carried out a successful test flight.

TECHNOLOGY

RAMJETS

Many spaceplane concepts rely on ramjet technology to help them fly through the atmosphere. A ramjet is a jet engine with few moving parts – rather than using turbines to draw in air for combustion, it relies on its own forward motion to force air into it at high speed. The shape of the engine then compresses and heats the air until fuel is injected, and the combustion produces thrust. Ramjets are often incorporated into the airframe of an aircraft – as seen in NASA's X-43A (right). Because they rely on their own forward motion, they are only effective at speeds of 1,600kph (1,000mph) or more, so another engine is needed to reach these speeds. Fortunately, the rocket engines needed to operate in space can also be used to gain to speed.



Chinese manned spaceflight

Early in the 21st century, China embarked on an ambitious project to equal the achievements of the 20th-century superpowers, sending men into orbit and perhaps beyond.

DIVINE VESSEL
The Shenzhou spacecraft shares its three-part layout with the Russian Soyuz capsules, but is somewhat larger and has an extra pair of solar arrays on the orbital module.

20 November 1999
The unmanned Shenzhou 1 test rocket is successfully launched.

5 January 2003
The safe return of Shenzhou 4 after six days in orbit opens the way for a Chinese manned spaceflight.

15 October 2003
Yang Liwei becomes the first Chinese taikonaut, aboard Shenzhou 5.

16 October 2003
Shenzhou 5's re-entry module returns Yang to Earth after 14 orbits and 21 hours.

16 March 2004
Automated experiments in Shenzhou 5's orbital module end.

30 May 2004
The Shenzhou 5 orbital module burns up.

12 October 2005
Shenzhou 6 carries China's first two-man crew into orbit.

16 October 2005
The Shenzhou 6 re-entry module returns to Earth in Inner Mongolia.

15 April 2006
Experiments aboard the Shenzhou 6 orbital module are completed.

Although China planned a manned spaceflight programme as early as the 1960s, its chief supporters fell victim to one of the government's periodic purges in the 1970s, and the plan seemed to be forgotten. There was some talk of Chinese cosmonauts flying aboard Mir in the 1980s, or even joining a Space Shuttle crew, but the world was taken by surprise when the Chinese government approved a new manned space programme, initially known as Project 921, in 1992.

The newly formed China National Space Administration (CNSA) benefited from an agreement signed with Russia in 1994, which gave them access to Soyuz capsules, blueprints, and Russian expertise, but despite an overall resemblance to the reliable Soviet spacecraft, the new vehicle, called Shenzhou (meaning "divine vessel"), is completely Chinese in design and manufacture. Like Soyuz, Shenzhou has three separate elements – an orbital module, a re-entry module, and a service module. However, it is significantly larger than Soyuz, and is fitted with two sets of solar arrays – one pair on the service module, the other on the orbital module. This allows the orbital module to continue powered operation even after it has been jettisoned from the rest of the spacecraft and the crew have returned to Earth.

Shenzhou 1, an unmanned development test, was launched in November 1999 by a CZ-2F Long March rocket. It orbited Earth 14 times, tracked by China's

LAUNCH OF SHENZHOU 6
A Long March CZ-2F powers into the sky at Jiuquan, carrying China's second manned mission. In contrast to the first mission, the Shenzhou 6 launch was broadcast live on television.

RETRIEVING CAPSULE
Engineers retrieve the Shenzhou 6 re-entry capsule from its landing site in Inner Mongolia's Siziwang Banner region. In contrast to early US and Soviet flights, all the Chinese Shenzhou missions so far have come down on target within a relatively small landing zone.

LANDING CELEBRATION
The landing-site team welcome back the crew of Shenzhou 6 after their five-day voyage. Fei Junlong (left) commanded the flight, with Nie Haisheng as his flight engineer.

network of shipborne monitoring stations, before the re-entry sequence was triggered and the central module landed safely in Inner Mongolia.

The first taikonaut

Three more test flights followed, using dummy astronauts and animals to study conditions and life-support systems. Each of these flights carried experiments onboard, some of which remained in space with the orbital module for extended missions.

BIOGRAPHY

YANG LIWEI

Born in China's Liaoning province, the first taikonaut Yang Liwei (b.1965) was fascinated by aviation from his youth and, after joining the People's Liberation Army in 1983, enrolled in its Aviation College No. 8. After graduation, he became a fighter pilot, accumulating more than 1,300 flying hours in his Air Force career. Selected as a candidate for manned spaceflight in 1998, he went through five years of intensive study and simulation at the Astronaut Training Base in Beijing. This led to his selection as the pilot for the Shenzhou 5 mission in October 2003.

The launch of Shenzhou 5 saw the first flight of a Chinese spacefarer (or taikonaut). Although the Chinese authorities announced the flight in advance, they did not permit a live broadcast of the launch, presumably in case something went wrong. Yang Liwei (see panel, left) blasted off from Jiuquan at 09:00 local time on 15 October 2003. He completed 14 orbits of the Earth before landing in Inner Mongolia in a virtual repeat of the Shenzhou 1 mission. Yang remained in the re-entry module throughout the flight, but experiments onboard the orbital module continued to function for five months after the craft had been abandoned in space.

While the early days of the Space Race were marked by frequent competitive launches, the Chinese seem to have adopted a more measured strategy – the world had to wait two years for the launch of Shenzhou 6. This time, two taikonauts remained in orbit for almost five days. They entered and worked in the orbital module for the first time, and continued to test the spacecraft's systems.

A future in space

The Chinese space programme can at times be just as inclined to secrecy as the old Soviet one, with little warning of launches when they come. China seems intent on taking its own route to space (though the CNSA has also discussed collaborative missions with foreign space agencies such as ESA), and occasional political speeches and statements from the project's leaders suggest that China is in space for the long term. There are plans for a space station in the early 2010s, a manned lunar landing by 2024, and for missions to Mars after 2040, with spaceprobes venturing out across the Solar System ahead of these manned missions.

Looking further afield than anyone in the West would dare, Shenzhou's chief designer Qi Faren has even spoken seriously of the future exploration of Saturn and its moons.

STACKING SHENZHOU 5
Technicians at Jiuquan Satellite Launch Centre oversee attachment of Shenzhou 5, in its protective fairing, to its Long March CZ-2F rocket. Jiuquan is China's current manned launch site, but future Moon missions will launch on a heavy-lift CZ-5 from Wenchang.

Back to the Moon

In the wake of the *Columbia* disaster, the future of American manned spaceflight was mired in uncertainty. But in 2004 President Bush gave NASA a new mission to fulfil, beginning with a return to the Moon.

The loss of *Columbia* sealed the fate of the Space Shuttle – even as the recovery teams swept Texas for debris, it was clear that all hope of Shuttle flights ever becoming routine was gone. If it had not been for NASA's international commitment to finish the ISS, the Shuttle might never have flown again. As it was, America would do what was needed to get the station finished, but then the Shuttle would be retired and other spacecraft could take on the job of crew transfer and resupply.

BUSH'S VISION
The sweeping changes announced by the President in January 2004 were the result of months of discussion with NASA officials.

A complete withdrawal from manned spaceflight was never on the cards – the image of the heroic American astronaut is too deeply embedded in the national psyche for that – and a new spacecraft would clearly be needed, but what would its role be? A glorified ferry to service the ISS, or something more? That decision, and a lot else, depended on NASA's future role in spaceflight: despite a number of false dawns, the agency had sorely lacked a central mission since the heyday of Apollo.

To redefine NASA, the Bush administration returned to a concept not seen in manned spaceflight since the 1960s – exploration. While retaining the benefits of a presence in Earth orbit, the agency and the nation should direct their gaze further afield, dusting down and revising the draft moonbase concepts and Martian exploration proposals of the last few decades and finally making them into a reality.

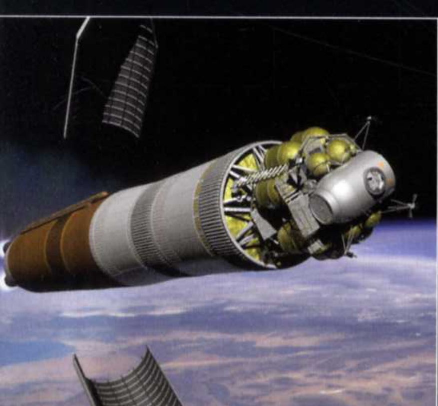
President Bush announced the new Vision for Space Exploration in January 2004. His deadlines were not as challenging as Kennedy's had been four decades previously – NASA should fly its new Crew Exploration Vehicle (CEV) by 2014 and attempt to land on the Moon by 2020. Nevertheless, the new mission seems to have galvanized the space agency. However, the plan also has many critics, ranging from planetary scientists who think the money would be better spent on unmanned exploration to "new space" advocates who see the project, and NASA, as relics of a monolithic approach that should be swept away in favour of commercial enterprises (see p.308).

The new explorers

The politicians left the detail of the new plan to the experts. As in the early 1960s, the first task was to work out the mission profile and the constraints it would place on the spacecraft, and NASA settled on a complex but versatile plan involving both Earth-

NASA'S NEW TECHNOLOGY
Development of the Orion CEV began with the building of a full-size mockup (above) at Johnson Space Center. Although the CEV's shape resembles the Apollo Command Module, it is three times the size and designed to carry a crew of four. Improved heat shielding and a touchdown on land will make each capsule reusable up to ten times. Meanwhile, the development of new spacesuits and roving vehicle prototypes (opposite) got underway in 2006.

FUTURE MOON LANDING
This artist's impression shows astronauts at work around an LSAM. The larger scale of the new spacecraft compared to the two-man Apollo version is clear, and the LSAM will also be capable of unmanned missions.



Earth-orbit rendezvous

An LSAM and Earth Departure Stage are put into space by an Ares rocket. An Orion crew vehicle docks with the LSAM later.

Translunar flight

The Departure Stage fires to put the docked spacecraft on its way to the Moon. Once this is achieved, the stage is discarded.

Lunar-orbit separation

The entire crew then board the LSAM for the descent to the lunar surface, while the CEV remains in orbit, unmanned.

and lunar-orbit rendezvous, with two launches for each mission. New launch vehicles would also be needed – a small one to carry the CEV, and a heavy lifter to take cargos such as the Lunar Surface Access Module (LSAM) into orbit. NASA named the new generation of launch vehicles Ares, from the Greek name for Mars (see panel, right). The CEV will be called Orion, while the entire programme is now officially Project Constellation.

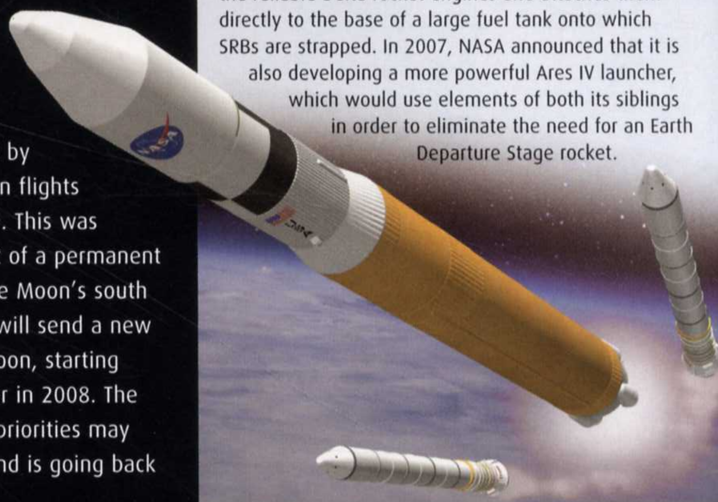
NASA chose Lockheed Martin to build the Orion spacecraft in August 2006, with a timetable that requires a first flight by 2014. The CEV will incorporate the latest in flight technology, and will at least temporarily act as NASA's transport to the ISS before the Moon missions get underway in the late 2010s – although the agency is also sponsoring the development of commercial low-Earth-orbit vehicles that it hopes will take Orion's place on these shorter trips.

In 2006, NASA announced an initial timetable of Constellation launches that would see rocket tests by the end of the decade, manned Orion flights in 2014, and a lunar landing in 2019. This was soon followed by the announcement of a permanent lunar base to be established near the Moon's south pole by 2024. In preparation, NASA will send a new wave of unmanned probes to the Moon, starting with its Lunar Reconnaissance Orbiter in 2008. The project's schedule may drift and its priorities may change, but at last, it seems, mankind is going back to the Moon.

TECHNOLOGY

ARES LAUNCHERS

NASA's new launch vehicles build on the best and most reliable aspects of Shuttle technology, incorporated into a more traditional and far safer design. The manned rocket, Ares I, is effectively an extended version of the Shuttle Solid Rocket Booster (SRB) with a liquid-fuelled second stage. The Ares V cargo rocket, meanwhile, takes the reliable Delta rocket engines and attaches them directly to the base of a large fuel tank onto which SRBs are strapped. In 2007, NASA announced that it is also developing a more powerful Ares IV launcher, which would use elements of both its siblings in order to eliminate the need for an Earth Departure Stage rocket.

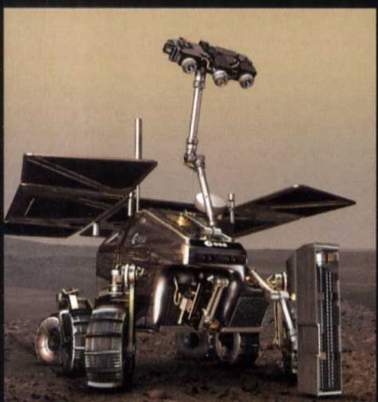


"We will build **new ships to carry man forward** ... to gain a new foothold **on the Moon** ..."

President George W. Bush, 14 January 2004

Onwards to Mars

Looking beyond its return to the Moon scheduled for 2020, NASA is turning its attention to a far more ambitious Mars mission. By then, a small army of new probes will have assessed the conditions that await human visitors.



EXOMARS ROVER
Europe's next Mars mission, planned for the mid-2010s, will put a robotic field biologist on Mars. The roving laboratory will search for signs of past and current life, but also investigate the nature of the Martian soil to assist future manned missions.

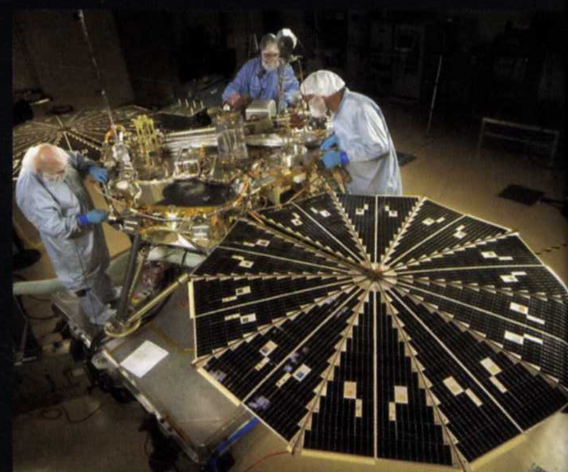
A trip to Mars is the next obvious step in human exploration of the Solar System, but huge new challenges will have to be overcome. Nevertheless, NASA's new Vision for Space Exploration has probably the best chance since the Apollo era of actually putting a man on Mars.

To date, the agency has not officially endorsed even a basic mission profile, but there are several independent proposals and, with some knowledge of the difficulties, we can at least get a glimpse of what may be involved in a manned Mars mission.

Assuming it is designed to take advantage of the periodic close approaches between Mars and Earth, a round trip to Mars would be a roughly three-year mission. The real dangers of such a long spaceflight will lie in the continuous exposure to radiation and the dangerous first steps on Mars after months of muscle deterioration in zero gravity (for even though the spacecraft will be moving at high speed, its astronauts will be weightless as soon as it stops accelerating). For these and other reasons, some form of radiation shielding around the spacecraft will certainly be needed, and if possible the design should generate artificial gravity (see panel, below).

Another major challenge of a manned mission is the sheer amount of fuel it requires: the spacecraft must break free of Earth's gravity, accelerating enough to reach Mars in a reasonable time, and then decelerating to drop into orbit. Getting to and from the Martian surface will require even more fuel, as will the journey back to Earth.

Shielding, artificial gravity, and a heavy fuel load will all increase the size and mass of a Mars spacecraft at the start of its long mission, and any all-in-one mission will be far too large to launch directly from Earth – instead it will probably be assembled in Earth orbit from separately launched components.



PHOENIX LANDER
NASA's next Mars mission, due to touch down in 2008, has fan-like circular solar arrays. It will target the Martian north pole, hopefully with more success than 1999's Mars Polar Lander (see p.273).

Direct to Mars

One ingenious solution to the many problems with such a mission was developed in the 1990s by the American Robert Zubrin, founder of the Mars Society. Zubrin's Mars Direct mission involves sending an automated Earth Return Vehicle (ERV) to land on Mars ahead of the main mission's departure. The ERV would contain equipment and chemicals to manufacture at least 96,000kg (211,000lb) of oxygen and methane propellants using carbon dioxide extracted from the Martian atmosphere.

Once the ERV had generated sufficient fuel, a second craft called the Mars Habitation Unit (MHU) would set out, carrying a crew of four and generating

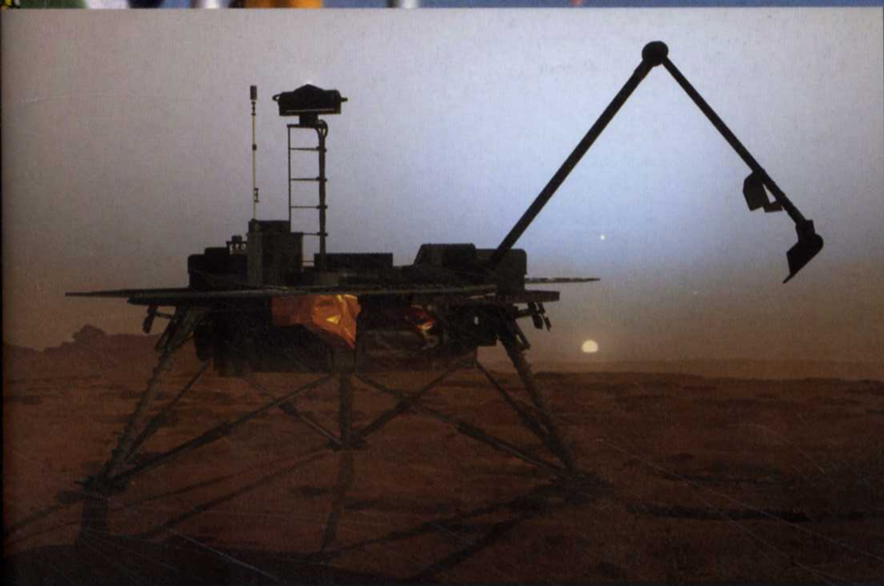
VISION OF MARS
(Right) A NASA artist's impression shows the crew of a future Martian manned mission setting up equipment during exploration of the Martian poles.

TECHNOLOGY

ARTIFICIAL GRAVITY

The easiest way of creating artificial gravity is simply to set a spacecraft spinning. The centrifugal force this generates will produce an effect equivalent to gravity, with objects pushed away from the spacecraft's centre of mass, as seen in countless science-fiction films. However, this is not ideal in a small spacecraft, since all the walls effectively become floors. One way to produce artificial gravity in a consistent direction is to move the centre of mass outside the spacecraft, and this can be done by tethering it to a similar mass and setting the entire assembly spinning. The crew of Gemini 11 briefly managed to do this in 1966 (see p.110). In the Mars Direct proposal, artificial gravity is generated during the journey to Mars by tethering the Mars Habitation Unit to its spent upper rocket stage, while on the return it is done using the exhausted engine of the Earth Return Vehicle as a counterweight.

FUTURE SPACESUIT
Astronaut Andrew Feustel rehearses a 10km (6 mile) low-gravity walk in a prototype hard-shelled spacesuit. Similar suits will be needed for both the Project Constellation lunar landings and the future exploration of Mars.

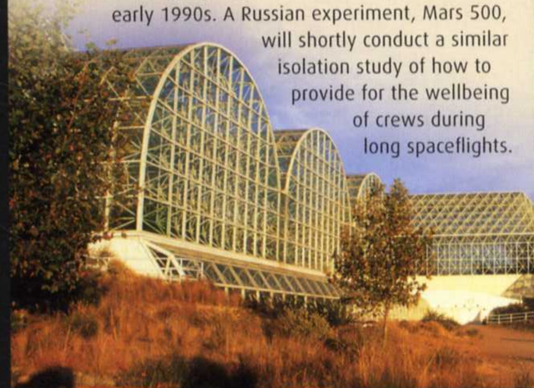


PHOENIX IN WINTER
The Phoenix Lander is a strictly short-term mission to investigate subsurface ice and signs of life around the Martian North Pole. Because Mars has a similar tilt to Earth, the polar regions are dark for part of the year. Robbed of sunlight and covered in winter frosts, the probe will soon cease to function when winter sets in.

HISTORY FOCUS

REHEARSALS FOR MARS

Early Martian astronauts will be on the planet for a long time – the shifting positions of Earth and Mars in their orbits ensure that close approaches suitable for the journey between planets happen only every couple of years. Assuming they have enough supplies, how will the astronauts fare physically and psychologically? To answer this question, several experiments have been carried out – most famously, the establishment of Biosphere 2, a self-contained colony in the Arizona desert, where eight people lived for two years in the early 1990s. A Russian experiment, Mars 500, will shortly conduct a similar isolation study of how to provide for the wellbeing of crews during long spaceflights.



its own artificial gravity. Reaching Mars in about six months, the MHU would slow itself by aerobraking and land close to the waiting ERV. At the end of the surface expedition, the astronauts would use the ERV to launch themselves on the trip back to Earth.

The ERV proposal dramatically reduces the weight of a Mars spacecraft and also gets around the potential risks of landing a fuel-laden rocket on the planet. Disadvantages of the original Mars Direct scheme included the need for a Saturn V-class launcher to send the ERV direct from Earth and reliance on its onboard chemical plant for the return journey. A NASA-developed variation from 1997 would put a fully fuelled ERV in Mars orbit, land a Mars Ascent Vehicle (MAV), fuel plant, habitat, and other equipment on the Martian surface, and then send a small descent vehicle along with the crew.

Other suggestions involve assembling the various elements of the Mars mission in Earth orbit (perhaps using the ISS as a construction base) to avoid the need for a huge new launcher. Based on the specification for the Ares launchers and the profile for the Constellation lunar missions, it seems likely that any NASA Mars mission will indeed feature some orbital construction. The agency also originally wanted methane engines on its LSAM lunar lander, suggesting it likes the idea of on-site Martian fuel production (although the idea had to be abandoned due to reasons of time and cost). It will doubtless be some time before the various discussions and arguments crystallize into a single coherent plan.

Robot explorers

In the meantime, NASA is concentrating on laying the foundations. A new wave of Mars probes, begun by the Mars Reconnaissance Orbiter and continued with the Phoenix Lander and ExoMars, will travel to the planet and investigate the burning scientific questions of water and life, while scouting out potential sites for manned landings. Elsewhere, spacecraft and rover designs suitable for the surface of Mars are being tested in hostile desert conditions, and scientists conducting biomedical experiments are searching for volunteers to spend months on simulated space missions (see panel, above).

New horizons

Over the next decade, new spaceprobes are scheduled to explore the extremes of the Solar System, from baking Mercury to the frozen outer worlds beyond Neptune.

Plans for future unmanned spaceprobes are notoriously prone to change – priorities alter, budgets spiral out of control, and of course things go wrong. Even if a probe survives launch and reaches its target, computers can develop bugs, or physical apparatus can jam or break: the history of unmanned space exploration is littered with examples. However, some future plans are more certain than others – and barring accidents, at least a handful of probes currently in the late stages of development or already on the way to their destinations should be surprising us with new discoveries before long.

MESSENGER to Mercury

The Mercury Surface, Space Environment, Geochemistry and Ranging mission (fortunately known by the acronym MESSENGER) embarked on a lengthy journey to the innermost planet on 3 August 2004. Despite Mercury's proximity to Earth, the probe must fly through a complex series of gravity-assist manoeuvres in order to pick up speed and gain enough energy to match Mercury's orbit. This convoluted route is needed because, unlike the Mariner 10 probe that first visited Mercury in the 1970s, MESSENGER will go into orbit around the planet.

After its arrival in March 2011, MESSENGER's instruments will go to work, gathering data for at least a year. As well as cameras, the probe carries spectrometers for analyzing minerals and gases, a laser altimeter for measuring the height of the surface, and instruments to map Mercury's gravitational and magnetic fields.

For such a nearby planet, we know surprisingly little about Mercury, and we have seen less than half of its surface. MESSENGER should change all this, turning the mysterious little ball of rock into a fascinating new world in its own right.


ENCAPSULATING MESSENGER
Workers at the Astrotech Space Operations facility near Kennedy Space Center carry out final tests on MESSENGER (far right) before the finished probe is unveiled to the world's media on 14 September 2004 (right).

MESSENGER FROM EARTH
After flying past Earth one year after launch, MESSENGER's route takes it twice past Venus to speed it up and direct it Sunwards. Three flybys of Mercury and a series of engine burns will gradually adjust the probe's path until finally it will rendezvous with Mercury in the correct trajectory to slip into orbit.

Into the frozen deep

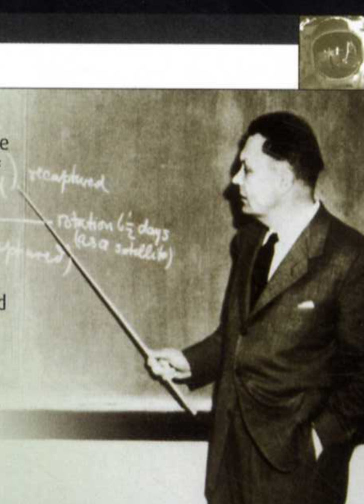
Since the planets were officially re-classified in 2006, NASA can claim to have sent probes to all the major worlds of the Solar System, but what of the former ninth planet, Pluto? Astronomers now know that it is really a dwarf planet, part of the Kuiper Belt, a ring of icy objects beyond Neptune. The belt was proposed by Gerard Kuiper (see panel, below) in 1951, but it took four decades for modern telescopes to bring it into view.

In January 2000, NASA launched a probe that is now hurtling towards this mysterious region in a race against time. New Horizons was the fastest spacecraft ever to leave Earth, and a boost at Jupiter will send it across the realm of the outer planets in just eight years, passing Pluto in 2015, before continuing into the cold depths of the Kuiper Belt.

The reason for this blistering pace is that Pluto is a changing world. It follows a 248-year elliptical orbit that, between 1979 and 1999, brought it closer

BIOGRAPHY

GERARD KUIPER



Dutch-born astronomer Gerard Peter Kuiper (1905–1973) had a career that ranged across the Solar System. After studying at the University of Leiden, Kuiper left to work in the United States, joining Chicago University's Yerkes Observatory in 1937. While working here, he discovered Uranus's moon Miranda and Neptune's moon Nereid, found that Titan has an atmosphere, and predicted the existence of what would become known as the Kuiper Belt. In 1960, he moved to Tucson to become the first director of the University of Arizona's new Lunar and Planetary Laboratory. He also served as chief scientist on NASA's series of Ranger lunar crash-landers.

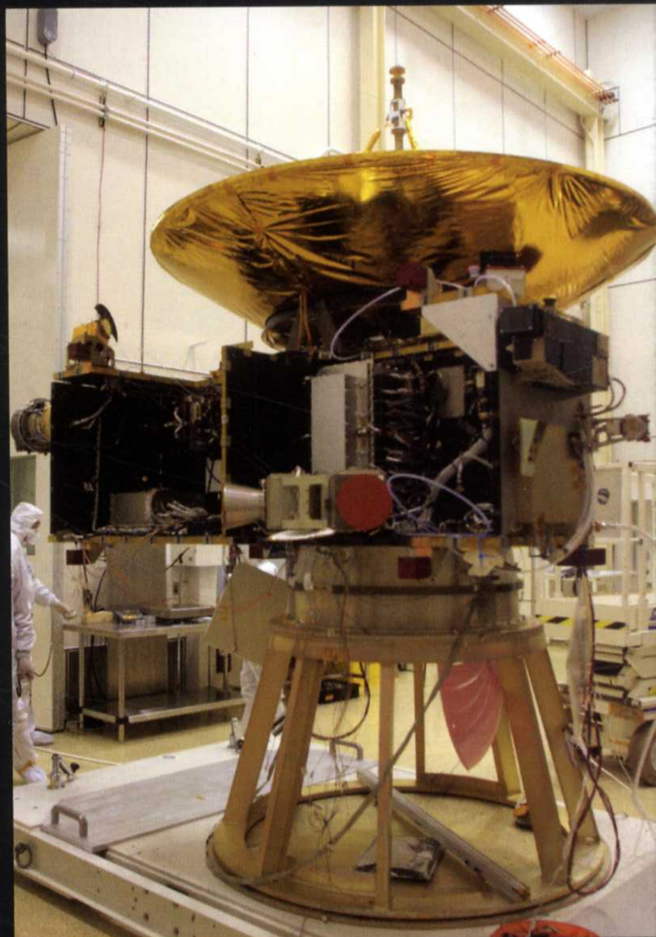
to the Sun than Neptune. During this "perihelion passage", ice on Pluto's surface evaporated to form a thin atmosphere, and NASA hopes that New Horizons will arrive in time to study the gas around Pluto before it freezes again, probably in the late 2010s.

Grand plans

Over the next decade, a dozen or more new spaceprobes are sure to be launched. Most will go to the Moon and Mars as preparation for new manned missions gather pace, but which other plans will make it off the drawing board?

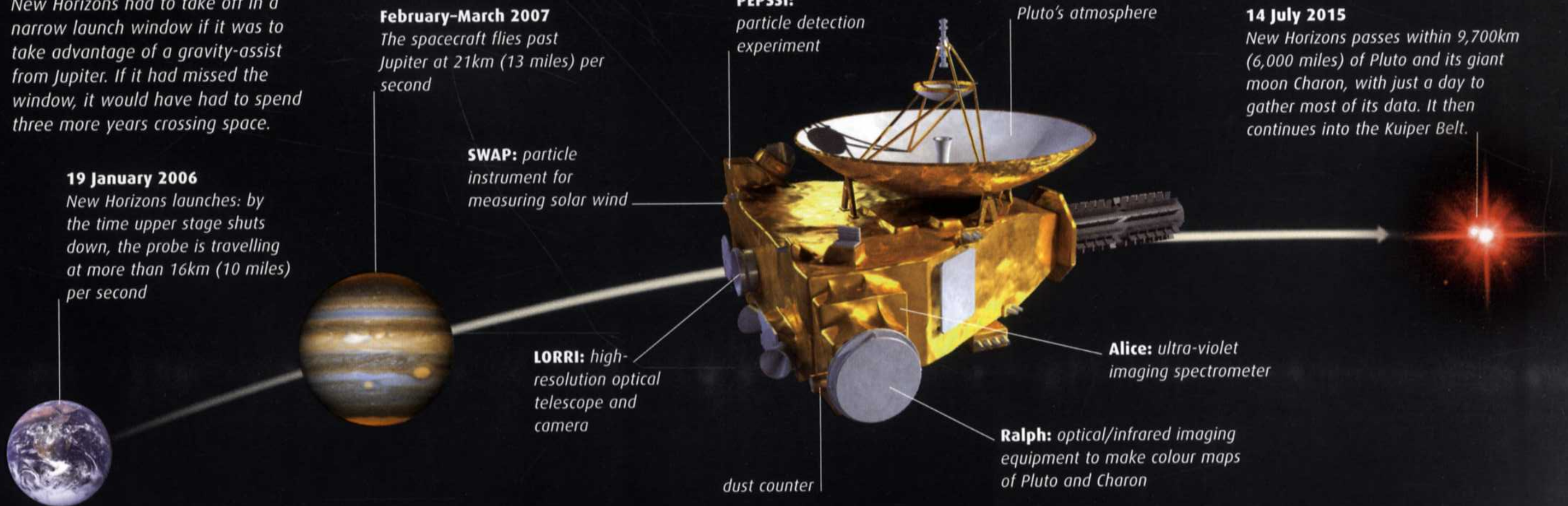
Dawn is a certainty – a NASA mission to be launched in 2007 which, if all goes well, will fly past and investigate the two largest denizens of the asteroid belt, Vesta and Ceres, in 2011 and 2015 respectively. Powered by an ion drive similar to that used on Deep Space 1 (see p.282), it will be the first spacecraft ever to go into orbit around two separate alien worlds.

Further afield, ESA and JAXA plan to follow MESSENGER with their own Mercury orbiter, BepiColombo, and after the cancellation of NASA's plans for a Jupiter Icy Moons Orbiter, ESA hopes to fill the gap with a mission to investigate Europa.



IN THE LAB
The New Horizons spacecraft is seen here under construction at Johns Hopkins University Applied Physics Laboratory in Maryland. In order to fly at high speed to the outer Solar System, the probe's weight had to be kept to 479kg (1,054lb), including propellant for in-flight manoeuvres.

TO PLUTO AND BEYOND
New Horizons had to take off in a narrow launch window if it was to take advantage of a gravity-assist from Jupiter. If it had missed the window, it would have had to spend three more years crossing space.



The rise of commercial spaceflight

The last decade has seen a major shift in attitudes to manned spaceflight and exploration – they are no longer the preserve of superpower governments but now also the stuff of holiday brochures. The rise of space tourism and privately developed launch vehicles will open up spaceflight to many more people.

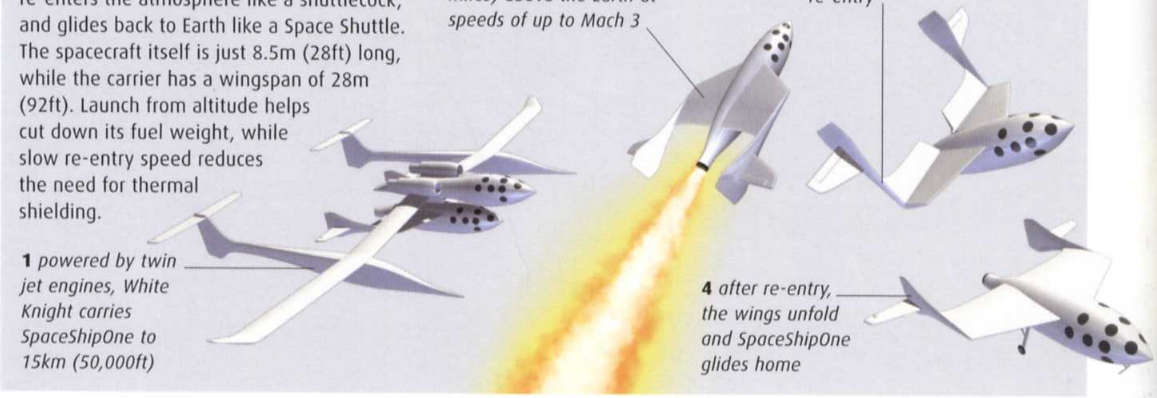
The idea that one day we might holiday in space would have seemed quite feasible to Wernher von Braun and his colleagues when they wrote their *Collier's* articles in the early 1950s. Even as late as 1968, Stanley Kubrick and Arthur C. Clarke could show a commercial space shuttle plying its trade between the Earth and orbit in their film *2001: A Space Odyssey* without being dismissed as fantasists.

But as Cold War politics and constant budget cuts got in the way, the idea that space would ever be opened up to the masses faded away, or at least retreated into an unimaginably distant future. Space travel, it seemed, would only ever be open to the hardened professionals – pilots, engineers, and the occasional lucky scientist. It's all the more surprising, then, that today the pendulum has swung the other way, with space tourism a reality and a number of companies and respected businessmen developing plans to make it cheaper and more accessible.

TECHNOLOGY

SpaceShipOne

X Prize winner SpaceShipOne has a totally unique flight profile. Taken to high altitude by the White Knight carrier aircraft, it fires its rockets to enter a suborbital trajectory, re-enters the atmosphere like a shuttlecock, and glides back to Earth like a Space Shuttle. The spacecraft itself is just 8.5m (28ft) long, while the carrier has a wingspan of 28m (92ft). Launch from altitude helps cut down its fuel weight, while slow re-entry speed reduces the need for thermal shielding.



Tourists in orbit

The first space tourists, admittedly, have been drawn from the ranks of the super-rich, and assisted into orbit by eager government agencies – especially the Russian Space Agency. For an organization operating on a relative shoestring, the prospect of bankrolling the ongoing Soyuz launches with passengers paying $20 million a time has proved too tempting to resist. For their money, those who can afford it get an intensive programme of preparation at the Gagarin Cosmonaut Training Centre and a trip to the ISS in the "spare" seat of a Soyuz TMA spacecraft. Attitudes aboard the ISS have changed since the first space tourist, US entrepreneur Dennis Tito, was grudgingly accepted by NASA. Today, tourists are made more welcome and given mundane but useful tasks to help with the running of the station. Despite the high cost, the Russian Space Agency has a waiting list for its flights, and since Tito's mission of 2001, several others have flown. These included South African businessman Mark Shuttleworth, US electronics manufacturer Gregory Olsen, and Anousheh Ansari, an Iranian-born American who made her money in the software industry.

X PRIZE ALSO-RANS

The other X Prize competitors reached various stages of completion before SpaceShipOne stole the glory. Thunderstar (above) was a British-built rocket that has continued in development since 2004. Ascender (right) was an unfunded concept for a spaceplane using jet engines in the atmosphere and rockets at high altitude.

Competing for space

Ansari is where the boundaries between present and future space tourism merge, for money from her and her brother-in-law, Amir Ansari, has helped drive the development of the commercial launch industry. They were major sponsors of the Ansari X Prize, a $10 million competition to find a reusable piloted spacecraft that could travel to an altitude of 100km (60 miles) twice within two weeks.

The prize spurred an international race that drew 26 competitors and proved an effective way to kick-start the industry. It was ultimately won when the TierOne project's SpaceShipOne (see panel, above) made suborbital hops on 29 September and 4 October 2004. SpaceShipOne was a pioneer in more ways than one, with a truly ingenious design by Burt Rutan (see panel, opposite) that got around some of the major drawbacks of traditional launch vehicles instead of seeking merely to imitate them.

READY FOR FLIGHT
SpaceShipOne is docked to the underside of White Knight prior to launch. The spacecraft now hangs in the Smithsonian Institution alongside the Bell X-1.

VIRGIN GALACTIC
An artist's impression of SpaceShipTwo, currently under construction. The scaled-up version will carry two pilots and six paying passengers.

Package tours to space

The X Prize appears to have done its job, for even before the qualifying flights British entrepreneur Richard Branson fixed a deal with TierOne to develop a larger SpaceShipTwo for use by Virgin Galactic, a commercial tourism venture. Other X Prize runners-up have also taken their ideas to market, and the first in a new wave of space tourists should be flying by 2010. Elsewhere, too, a new spirit of enterprise seems to have gripped the spaceflight community. Jeff Bezos of Amazon.com has formed a company called Blue Origin, which appears to be building on the DC-X single-stage-to-orbit concept of the early 1990s (see p.299) to produce a commercial spacecraft called New Shepard.

The X Prize itself has become something of a phenomenon, spawning new competitions in aerospace and other fields. And even NASA has seen the benefits of competition, setting up a series of Centennial Challenges and investing half-a-billion dollars in contracts with two private aerospace companies who produced winning designs for a new ISS transport vehicle.

FEMALE SPACE TOURIST
Anousheh Ansari during training for her trip to the ISS. Ansari launched aboard Soyuz TMA-9 on 18 September 2006, and spent nine days aboard the station before returning to Earth on 29 September.

BIOGRAPHY

BURT RUTAN

The designer of SpaceShipOne is Oregon-born, California-raised Burt Rutan (b.1943). He designed his first aircraft when just eight years old and took his first solo flight aged 16. After studying aeronautical engineering, he worked on aircraft testing at the US Air Force's Edwards Air Force Base. In 1974 he set up an aircraft factory in California's Mojave desert. Specializing in strong, light, and fuel-efficient aircraft, in 1982 it became Scaled Composites. Before the flight of SpaceShipOne in 2004, his most famous aircraft was the *Voyager*, which in 1986 became the first aircraft to fly non-stop around the world.

Out of the cradle

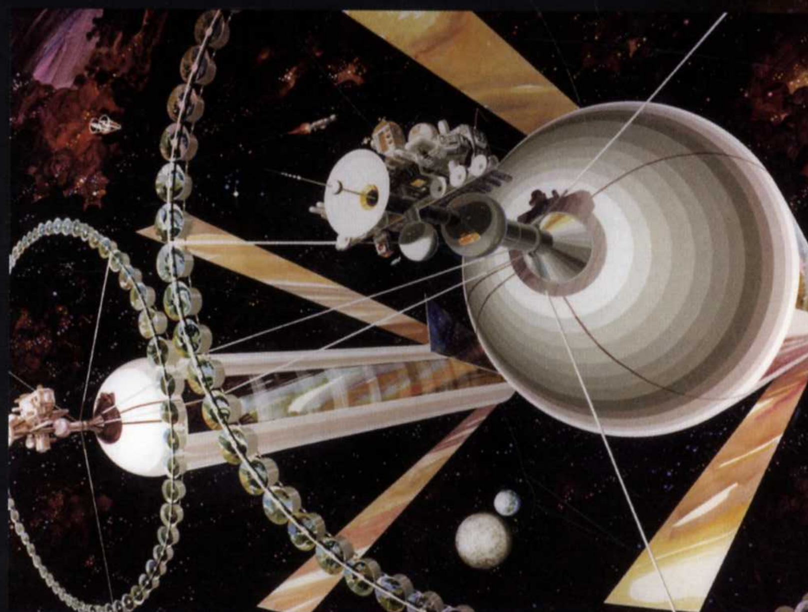
What is the future of humanity in space? Will mass space travel and the colonization of other worlds ever become a reality, or will space travel remain forever the preserve of an elite few?

More than a century ago, Konstantin Tsiolkovskii was already certain of the answer – he spoke eloquently of mankind's need to spread its wings and journey to other worlds. Oberth, Goddard, von Braun, and Korolev were among the many who agreed with him and strove to fulfil his original dreams. And yet, just as technology reached a point where such dreams could be a reality, political realities intervened and the future was stolen away.

Today, there are many who argue that the manned exploration of space is an expensive diversion from problems on Earth – wars, poverty, and environmental crisis. Ironically, the revolution in ecological awareness that created a generation of critics can be traced in part to 1968, when those first famous pictures of the Earth alone in space were sent back by the astronauts of Apollo 8.

By the 1990s, manned spaceflight risked becoming an irrelevance. Even many enthusiasts felt that the retreat to Earth orbit was a diversion from the real aims of exploring the Solar System and settling other worlds. Robert Zubrin (see p.304) argued that such an approach was like abandoning exploration of the Americas after Columbus.

However, the sudden appearance of space tourism and the redirection of NASA to manned exploration beyond Earth orbit have seen the start of what may be a rapid change. Continuing Zubrin's analogy, enthusiasts for this new age of democratic space exploration have pointed out that it also took several decades after those first pioneering voyages for the settlement and exploration of the New World to begin in earnest. Today, NASA has plans for its first moonbase and a future directive to continue to Mars. China is only taking its first steps into space, yet it is already looking as far afield as Mars and Saturn. And the enterprising space tourism community plans to follow its first wave of suborbital vehicles with spacecraft capable of reaching orbit and docking with existing or future space stations.



LIVING IN ORBIT
In one futuristic space habitat design, a pair of rotating cylinders 22km (13.7 miles) long and 6.2km (3.9 miles) across could support up to 20 million people continuing an independent civilization in space.

Visions of the future

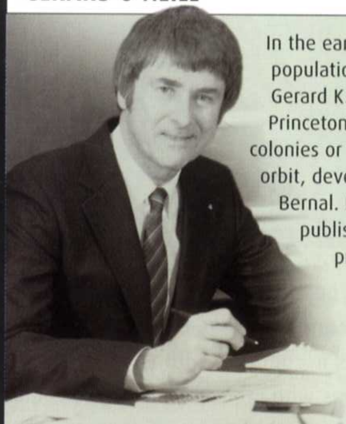
By the centenary of Sputnik 1, there may well be orbiting hotels and commercial flights to the Moon. The national space agencies may have established a base on Mars, and manned expeditions may be venturing further afield. Commercial exploration of the Moon and asteroids is already being planned – our satellite is rich in mineral resources, and any major space construction project would almost certainly use materials mined there instead of those launched at great expense from Earth. The asteroids, while harder to reach, are an even richer potential source of valuable minerals and metals.

We may never see space stations as ambitious as the space habitats suggested by the American physicist Gerard O'Neill (see panel, left), but self-sustaining colonies on other worlds seem increasingly plausible as we learn more about the

AMONG THE STARS
Physicist, historian of science, and one of the first to propose large-scale space habitats, Irishman John Desmond Bernal (1901–1971) predicted that one day the human race might split irrevocably into two species: Earthkind and Spacekind.

BIOGRAPHY

GERARD O'NEILL



In the early 1970s, concern about pollution and a growing population prompted many to consider radical solutions. Gerard K. O'Neill (1927–92), a professor of physics at Princeton University, suggested that large, self-sustaining colonies or "space habitats" could be established in Earth orbit, developing ideas that dated back to Tsiolkovskii and Bernal. In the mid-1970s, O'Neill and his colleagues published a series of papers that investigated the practical construction of such habitats, coming up with several detailed designs. In 1976 he published the influential book *The High Frontier: Human Colonies in Space*, and the following year he founded the Space Studies Institute, which funds the development of space-based industry.

"The Earth is **the cradle of humanity**, but mankind **cannot stay** in the cradle forever."

Konstantin Tsiolkovskii, 1903

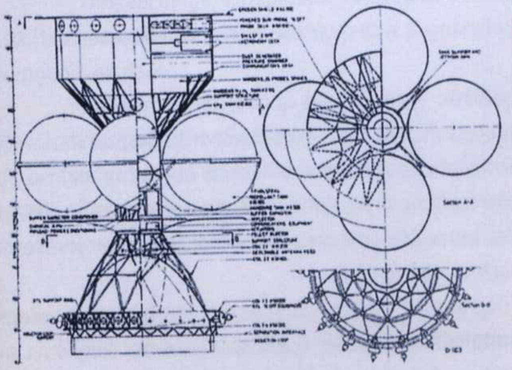
resources scattered across the Solar System. It may even be possible one day to terraform other worlds – seeding them with bacteria and gases that turn them eventually into hospitable environments, just as once happened on Earth itself.

Perhaps the ultimate dream is to venture across the stars and become truly independent of Earth and the Solar System. The distances involved are astronomical in the truest sense of the word – even the nearest star is 8,900 times more distant than Neptune. Expeditions to the stars may not happen for centuries and, if and when they do, they will almost certainly involve technologies that are currently in their infancy (such as nuclear propulsion – see panel, right) or not yet thought of. But as renowned cosmologist Stephen Hawking has said, the colonization of space may ultimately be the only way to ensure the long-term future of the human race.

TECHNOLOGY

NUCLEAR-POWERED SPACE TRAVEL

A journey to the stars in any reasonable timescale would require a new propulsion system – neither chemical rockets nor ion engines are up to the job. In the 1950s, US physicists Theodore Taylor and Freeman Dyson showed how a spacecraft might be powered instead by a series of explosions from small nuclear bombs detonating in its engine. A prototype of their Project Orion was tested with chemical explosives, but the use of nuclear material was so controversial that the concept was shelved. In the 1970s, the idea was revived by the British Interplanetary Society in Project Daedalus, the first detailed study of a practical starship design.



GLOSSARY

A4 The original designation of the early German rocket that flew as the V-2 missile.

ablative heat shield *see* **heat shield**

aerospaceplane A spaceplane designed to operate in the Earth's atmosphere using an alternative to rocket propulsion – usually a ramjet or scramjet.

Aerozine A rocket fuel consisting of a mixture of hydrazine and unsymmetrical dimethylhydrazine (UDMH).

Agena An upper rocket stage used on Thor, Atlas, and Titan launch vehicles and also as a docking target for several Gemini missions.

Almaz A Soviet military space-station design, flown as Salyuts 2, 3, and 5.

apogee The point in the orbit of a satellite or spacecraft where it is furthest from the Earth.

Ariane A series of European launch vehicles, operating since 1979 and widely used for commercial and scientific satellite launches.

Atlas A long-running US launch-vehicle series, originating from the first US Air Force Intercontinental Ballistic Missile.

attitude The orientation of a spacecraft or space station in space. Attitude adjustments can be made in roll, pitch, or yaw axes.

Baikonur Cosmodrome The main launch centre for the Soviet and Russian space programmes, located in Kazakhstan near the town of Tyuratam (originally named to deceive intelligence agencies into believing it was near the town of Baikonur itself).

ballistic A term used to describe a missile or spacecraft that makes its descent through the atmosphere under the influence of gravity and atmospheric drag alone, with no aerodynamic lift; the term also describes the behaviour of projectiles such as cannonballs.

boilerplate capsule A full-sized but not fully equipped replica of a finished spacecraft design, used in the early stages of testing for studying aerodynamic characteristics and other properties.

booster A small rocket attached to the side of a larger rocket stage to give extra thrust during launch.

Capcom An abbreviation for Capsule Communicator, normally the only person at NASA Mission Control who communicates with astronauts in space. Typically, the role is taken by a trained astronaut.

Centaur A type of upper rocket stage used to launch spaceprobes and satellites. The Centaur was the first rocket to successfully use high-energy cryogenic propellants.

Chang Zheng *see* **Long March rocket**

CM Abbreviation for the Command Module of the US Apollo spacecraft.

combustion chamber The part of a rocket engine where the fuel and the oxidant mix and combust, generating thrust against the forward-facing part of the chamber as the exhaust escapes from the nozzle at the rear.

comsat An abbreviation of communications satellite – a satellite used for receiving and re-transmitting signals to and from ground stations.

Cosmos A long-running series of Soviet and Russian satellites, comprising several different concealed programmes and often used to hide failed missions in other series.

cryogenic propellant A rocket propellant (fuel or oxidant) that must be stored at extremely low temperatures and which usually requires ignition in order to start a chemical reaction. Despite the problems in handling them, cryogenic propellants can be extremely powerful.

CSM Abbreviation for the combined Command and Service Module of the US Apollo spacecraft.

CZ *see* **Long March rocket**

Delta A long-running and highly successful series of US launch vehicles.

DOS A Russian acronym for Permanent Orbital Station, the Soviet space-station design developed in the late 1960s by the Korolev design bureau as an adaptation of the military Almaz station.

drogue parachute A small parachute used to slow a spacecraft down, usually directly after re-entry to the atmosphere and before the main parachute opens.

elliptical orbit An orbit with the shape of an ellipse (a "stretched circle"). As well as a centre, an ellipse has two foci, with the centre of mass being orbited at one focus. Because an orbiting object's speed is dependent on its distance from the mass that it orbits, it moves more slowly at one end of the ellipse than at the other.

Energia The Soviet/Russian space company formed from the former OKB-1 design bureau of Sergei Korolev. Also a heavy-lift rocket produced by the company for launching the Soviet Buran space shuttle.

equatorial orbit An orbit directly above the Earth's equator. Equatorial orbits are comparatively easy to reach because the Earth's rotation gives rockets an immediate boost if they are launched eastwards from on or close to the Earth's equator.

ESA The European Space Agency, formed from the merger of the European Launcher Development Organisation (ELDO) and the European Space Research Organisation (ESRO) in 1975.

escape velocity The speed at which a spacecraft must travel if it is to escape the Earth's gravitational field – 11.2km (7 miles) per second. It is not necessary to reach escape velocity in order to orbit the Earth.

ET Abbreviation for the large external fuel tank of the Space Shuttle.

flight deck In the Space Shuttle orbiter, the upper deck containing flight controls and seating for most of the crew during launch.

fuel One element of a spacecraft's propellant. The fuel mixes with an oxidant and combusts to create exhaust that pushes the spacecraft forward.

g force A measure of acceleration forces. 1*g* is typical Earth gravity, but during launch and re-entry spacefarers experience accelerations of several *g*.

geostationary orbit Also known as geosynchronous orbit. An orbit in which a satellite above the Earth's equator moves around the planet in the same direction as the Earth's rotation and with the same period (roughly 23 hours, 56 minutes). This means that the satellite remains over the same point on the equator and occupies a fixed point in the sky as seen from Earth. Geostationary satellites are ideal for weather-observation and comsats.

GPS An abbreviation for Global Positioning System – a network of satellites that allows a computerized Earthbound receiver to work out its position by receiving signals from three or more satellites in orbit. The original GPS system uses US NAVSTAR military satellites, but rival systems, including the Russian GLONASS and the European Galileo, are also often known simply as GPS.

gravitational slingshot *see* **gravity assist**

gravity An attractive force generated by a massive object, which pulls other objects towards it or holds them in orbit.

gravity assist A technique used to speed up and change the direction of a spaceprobe without burning fuel, by flying close to and "borrowing" a small amount of energy from a planet or moon.

ground station A radio receiving dish for communication with spacecraft, satellites, and spaceprobes.

Guiana Space Centre The launch site for the European Space Agency's Ariane rockets, at Kourou, French Guiana.

heat shield A protective layer that shields a spacecraft from the heat of re-entry. Most heat shields are ablative – they burn away during re-entry, carrying the heat away from the spacecraft. Other systems, such as the Space Shuttle orbiter's ceramic tiles, must absorb heat without transmitting it to the hull.

H-series rocket Japan's most widely used launch vehicle.

hydrazine A toxic chemical, commonly used as a rocket fuel because of its violent and spontaneous chemical reaction with many oxidants. It is used in the Space Shuttle's Auxiliary Power Units.

hypergolic propellant A rocket fuel that reacts spontaneously with its oxidant (avoiding the need for an ignition system), and which can usually be stored at relatively normal temperatures.

inertial guidance A guidance system that uses gyroscopes and accelerometers to calculate a vehicle's position and motion by dead reckoning (a method of navigation in which position is determined relative to a known point of departure using measurements of speed, heading, and time).

Inertial Upper Stage A large independent rocket stage used for putting satellites or other payloads into their final orbit or escape trajectory after they have been deployed to low Earth orbit by the Space Shuttle or another launch vehicle.

ion engine A propulsion system that uses the ionization of a chemical propellant in a strong electric field in order to generate thrust. Ion engines are very efficient but produce very small amounts of thrust for very long periods, contrasted with chemical rockets that produce large amounts of thrust for brief periods. They are usually powered by solar arrays.

JAXA The Japan Aerospace Exploration Agency, Japan's space agency, founded in 2003 from the merger of the Institute of Space and Astronautical Science (ISAS), the National Aerospace Laboratory of Japan (NAL), and the National Space Development Agency (NASDA).

Johnson Space Center (JSC) The site of NASA's main Mission Control and many other elements of its manned spaceflight programme, at Houston, Texas.

Juno An adapted version of the Jupiter-C used to launch some of the first US satellites.

Jupiter-C A modified Redstone missile used to carry the warhead of a Jupiter missile into space for re-entry tests.

Kennedy Space Center (KSC) The main US launch complex at Cape Canaveral in Florida. The Cape itself was known as Cape Kennedy between 1963 and 1973 in memory of the assassinated US President.

kick motor A small rocket motor built into a satellite and used to move it from low Earth orbit to its final location.

Korabl Sputnik Any of the later Soviet Sputnik satellite launches (4 onwards) that were in fact unmanned tests of Vostok spacecraft.

launch vehicle A complete vehicle, usually consisting of several rocket stages, boosters, and perhaps other components, used to launch payloads into space (often simply referred to as a rocket).

LH2 An abbreviation for liquid hydrogen, a powerful cryogenic fuel.

lifting body An aircraft or spaceplane that has only small wings, if it has wings at all. Lifting bodies rely on the shape of the fuselage to generate aerodynamic lift – they are typically triangular, with convex upper or lower hulls.

liquid-fuelled rocket A rocket in which fuel and oxidant are mixed together and react explosively, creating an expanding mixture of exhaust gases that escape through an exhaust nozzle. The reaction against the escaping gases pushes the rocket forwards. Liquid-fuelled rockets are more complex than solid-fuelled ones, but they are also more versatile, since the flow of fuel can be throttled, stopped, and restarted.

LM An abbreviation for the Apollo spacecraft Lunar Excursion Module (also LEM) – the spiderlike lander that actually put astronauts on the Moon.

Long March rocket A series of Chinese launch vehicles, used in manned and unmanned space programmes.

low Earth orbit An orbit a few hundred kilometres above the Earth, often abbreviated to LEO. Low Earth orbits are typically used by manned spacecraft and space stations, Earth-observing satellites, and as a temporary orbit for satellites later launched into higher orbits by an Inertial Upper Stage, a Payload Assist Module, or a kick motor.

LOX An abbreviation for liquid oxygen, a powerful cryogenic oxidant.

Marshall Spaceflight Center (MSFC) The principle US centre for launch-vehicle development and testing, developed from the US Army's former Redstone Arsenal facility at Huntsville, Alabama.

mass A property of the amount of material present in an object. Mass is unaffected by a gravitational field, unlike weight.

microgravity The term for conditions experienced in orbit – although the effects of gravity are much reduced, they are almost never completely absent.

mid-deck The lower habitable deck of the Space Shuttle orbiter, where equipment and, sometimes, experiments are stored.

MKS A Russian abbreviation for Reusable Space System, the Soviet attempt to develop a reusable space shuttle, also known as Buran.

Molniya orbit A highly elliptical, inclined orbit typically used by communications satellites for countries at high latitudes and named after the Soviet Molniya comsat system. A Molniya orbit sees a satellite spend a large amount of time visible in the skies of a particular part of the Earth, so that it can be easily tracked by ground stations.

monopropellant A class of rocket propellants that can act as both fuel and oxidant in the right conditions – one example is hydrogen peroxide.

multispectral imaging A technique used by remote-sensing satellites and other spacecraft that involves photographing areas at different wavelengths of light (different colours) and analyzing the images to bring out hidden features and reveal surface composition.

N2O4 Dinitrogen tetroxide, a commonly used hypergolic propellant that functions as an oxidant.

NASA The National Aeronautics and Space Administration, the US space agency, established in 1958 as successor to NACA, the National Advisory Committee for Aeronautics.

nozzle The exhaust outlet from the combustion chamber of a rocket. Exhaust gases typically escape from the combustion chamber at high temperatures through a narrow opening – the bell-shape of the nozzle forces the gases to expand rapidly, cooling them but increasing their speed so that they leave the rocket at up to ten times the speed of sound.

nuclear propulsion A theoretical propulsion system that would use the explosions of countless small nuclear devices to push a large spacecraft forwards. Nuclear propulsion is one potential way of accelerating a future starship to very high speeds.

OKB-1 The design bureau run by Sergei Korolev, Soviet Chief Designer of Rocket and Space Systems, from 1946 until his death in 1966. OKB-1 (sometimes known simply as Korolev) was responsible for much of the Soviet space effort. Since 1974 it has been known as Energia.

OMS The Orbital Maneuvering System, a pair of medium-sized rocket engines at the rear of the Space Shuttle orbiter that are used for adjusting the spaceplane's orbit and as retrorockets for re-entry.

orbit A path that one object follows around another, more massive one due to the force of gravity. An orbit traces a path through space along which the tendency of the object to fly off in a straight line is precisely balanced by the inward gravitational pull of the more massive object.

orbiter The proper name for the spaceplane element of the Space Shuttle system – the orbiter is the vehicle that reaches space, carries out its mission, and then returns to Earth.

oxidant A chemical, used as a rocket propellant, that undergoes a violent chemical reaction (combustion) with a fuel to generate exhaust gases and push a rocket forwards. In contrast to other types of engine, rockets require an oxidant as well as fuel because they must operate in a vacuum – other engines use oxygen from the atmosphere to burn their fuels.

payload The cargo that a launch vehicle delivers into orbit.

Payload Assist Module An independent rocket engine (smaller than an Inertial Upper Stage) attached to the base of a satellite released from the Space Shuttle, which is used to put the satellite into its final orbit.

perigee The point in the orbit of a satellite or spacecraft at which it comes closest to the Earth.

pitch The rotation of a spacecraft about its lateral (side-side) axis – for example, the angle from nose to tail of a Space Shuttle.

Plesetsk Cosmodrome The northern launch site for Soviet and Russian rockets, located close to the Arctic Circle and ideal for launching rockets into polar and high-inclination orbits.

polar orbit An orbit around the Earth that passes over (or very close to) the planet's poles. Typically used by Earth-observing satellites, a polar orbit allows the satellite to fly over most of the Earth's surface as our planet rotates beneath it each day.

Proton rocket A Soviet heavy-lift rocket used for launching heavy unmanned payloads such as space-station components.

R-7 A Soviet ballistic missile developed by Sergei Korolev, which forms the basis of the Soviet launch vehicles such as the Sputnik, Vostok, and Soyuz rockets.

ramjet A jet engine with few moving parts and no turbine, in which the speed of the aircraft through the atmosphere forces air into the engine at high pressure. Fuel is then added, with the combustion producing forward thrust. Ramjets are a key element of many aerospaceplane concepts, but they only function efficiently at supersonic speeds.

RCS An abbreviation of Reaction Control System, a series of small rocket engines (thrusters) scattered over the surface of a spacecraft and used for adjusting its attitude in yaw, roll, and pitch axes.

Redstone An American ballistic missile, developed by Wernher von Braun at Redstone Arsenal, which formed the basis for many early US launch vehicles.

re-entry The return of a spacecraft or other object into the Earth's atmosphere, during which it may be heated to extreme temperatures by friction with air molecules.

remote sensing The scientific study of the Earth from space.

retropack A set of discardable retrorockets strapped over the heat shield of the Mercury space capsule in order to slow it for re-entry.

retrorocket A rocket system used for slowing a spacecraft down rather than accelerating it. Retrorockets are used to begin re-entry to the Earth's atmosphere, or to slow spaceprobes down when they arrive at their destination.

rocket A propulsion system that drives a vehicle forwards through the principle of action and reaction and is capable of working in a vacuum. The term is also used casually to refer to entire launch vehicles.

roll The rotation of a spacecraft about its longitudinal (front-back) axis – for example, the tilt of the Space Shuttle's wings.

RP-1 A form of kerosone used as fuel in US rockets.

RSA An abbreviation for the Russian Federal Space Agency, formed in the early 1990s to manage various aspects of the former Soviet Union space programme. It is also known as Roskosmos.

RTG An abbreviation for Radioisotope Thermoelectric (or Thermal) Generator. An RTG uses heat produced by a sample of radioactive material to generate electricity for spaceprobes travelling in distant parts of the Solar System.

Salyut A series of Soviet space stations, incorporating both DOS (Salyuts 1 and 4) and Almaz (Salyuts 2, 3, and 5) stations, along with more advanced designs (Salyuts 6 and 7).

satellite Any object that moves around a more massive one due to the effect of its gravitational attraction. Satellites may be either natural (moons of the various planets) or artificial.

Saturn rockets A series of US heavy-lift launchers developed by Wernher von Braun in the early 1960s. Saturn I was based on a cluster of Redstone-type rockets, while the Saturn V used massive new engines and high-energy cryogenic propellants. Saturn IB was a hybrid, based on Saturn I but with an upper stage borrowed from the Saturn V.

scramjet A modified ramjet design in which combustion happens while the fuel and air are moving at supersonic speed.

shaft and trunnion NASA's term for the two axes in which the telescope and sextant of the Apollo guidance computer could be moved for targeting the Sun, stars, and other astronomical objects.

solar array A panel-like or wing-like arrangement of solar cells that converts sunlight into electricity for use by spacecraft.

solar sail An experimental propulsion method that uses the pressure of radiation from the Sun to push a spacecraft forwards. Solar sails are only capable of low acceleration but can reach very high speeds.

solid-fuelled rocket A rocket in which fuel and oxidant are mixed (usually with other chemicals) and stored in a solid state. When ignited, the rocket burns like a firework and gases escape through an exhaust nozzle, pushing it forwards. A solid-fuelled rocket can only be ignited once.

Soyuz A long-running Soviet spacecraft series, first launched in 1967 and later upgraded to Soyuz-T (1980), Soyuz-TM (1987), and Soyuz-TMA (2002).

Soyuz rocket A reliable Soviet/Russian rocket, derived from the R-7 missile and used to launch Soyuz spacecraft.

spaceplane A spacecraft with aerodynamic properties that allow it fly like an aircraft or glider for at least part of its time in the atmosphere.

spaceprobe An automatic vehicle sent to explore the Solar System away from Earth. Spaceprobes can include flyby missions, orbiters, and landers.

Sputnik rocket A Soviet rocket developed by Sergei Korolev from the R-7 missile and used to launch the first satellites.

SRB An abbreviation of Solid Rocket Booster, the rockets that assist the Space Shuttle during launch.

SSME An abbreviation of Space Shuttle Main Engine, the engines on the back of the Shuttle orbiter that burn fuel from the External Tank during launch.

stage A section of a launch vehicle that burns its fuel and then separates and falls away from the rest of the vehicle.

steering vane A movable deflector that can affect the path of exhaust from a rocket engine, controlling the direction in which the vehicle moves.

STS An abbreviation for Space Transportation System, the official name of the US Space Shuttle. Each Shuttle mission is given an STS designation followed by a number (though the numbers do not necessarily indicate launch order).

Sun-synchronous orbit A polar orbit that also circles the Earth's equator once a year, keeping pace with the angle of the Sun so that the ground below is illuminated at a constant angle.

telemetry A stream of data sent automatically from a spacecraft to Earth, containing information about the status of its onboard systems.

thrust The forward force generated by a rocket engine, often measured in kilograms-force (kgf). One kilogram-force is the force exerted by a weight of one kilogram in Earth gravity, equivalent to 9.81 newtons (the official SI unit of force).

thruster A small rocket engine used, for example, in attitude adjustments, such as in an RCS.

thrust structure A structure above a rocket engine that takes the brunt of the engine's forward thrust, thereby preventing it from pushing into its own fuel tanks.

Titan A long-running series of US launch vehicles, originating in the US ballistic missile programme.

TKS A Soviet ferry spacecraft that was developed for use with the Almaz space stations but was eventually used as the basis for several of the modules on the Mir station.

translunar Literally "moon-crossing" – the path taken by a spacecraft from the Earth to the Moon.

turbopump A high-speed pump that supplies fuel and propellant from the tanks of a liquid-fuelled rocket to the combustion chamber.

UDMH Unsymmetrical dimethylhydrazine, a widely used hypergolic rocket fuel.

V-2 The first large liquid-fuelled rocket, designed by Wernher von Braun and used as a missile by Germany during the Second World War.

Vernier engine A small rocket engine on a movable gimbal, mounted away from the main engines and used to steer a launch vehicle.

VfR An abbreviation of *Verein für Raumschiffahrt*, the German rocketry society of the 1930s.

Vostok rocket A Soviet launch vehicle, derived from the R-7 missile, used to launch the first manned spacecraft.

weight The force that acts on an object with mass in a gravitational field – while an object's mass remains constant, its weight may vary depending on the strength of local gravity.

weightlessness The condition of "free fall" experienced by people and objects when the effects of gravity are cancelled out in orbit.

yaw The rotation of a spacecraft around its vertical axis, the "crossways" orientation of a vehicle such as the Space Shuttle.

zero gravity *see* **microgravity**

INDEX

Page numbers in italic refer to illustrations.

T

U

V

W

X

Y

Z

ACKNOWLEDGMENTS

Author's acknowledgments

I'd like to thank everyone at DK, MP3, and elsewhere who helped turn this book from my personal hobby-horse into a reality. If I try to list them all I'll be sure to miss someone out, but particular thanks are due to Liz Wheeler and Peter Frances at DK and David Preston at MP3, without whom it really wouldn't have happened. I should give a special mention to everyone at South Florida Science Museum, Kennedy Space Center, and the US Space and Rocket Center, for their help and hospitality during our mad photographic dash around the United States.

Thanks also to friends and family for their interest, encouragement, and patience when I dropped off the radar during long periods of writing.

And I'd like to dedicate this book to my Mum and Dad – my never-failing sources of support and encouragement.

Publisher's acknowledgments

Dorling Kindersley would like to thank Tamlyn Calitz for her editorial contribution. Miezan van Zyl, Rebecca Warren, Rob Houston, Ed Wilson, and Manisha Thakkar also gave editorial assistance. Initial presentation design work was done by Mark Lloyd at On Fire and Peter Laws. Jim Jackson did additional design work, and John Goldsmid provided DTP design help.

MP3 acknowledgments

Many thanks to Rick Newman of HighTechScience.org for the kind loan of his space artefacts, and Elizabeth Dashiell and all the staff at the South Florida Science Museum, West Palm Beach for their assistance in photographing the collection; the Kennedy Space Center and the US Space and Rocket Center, Huntsville for granting access to their exhibits; Anatoly Zak and James Oberg for granting access to their private photography collections; Jody Russell at the Johnson Space Center and Houston One Great Photo Lab for processing help; Dave Shayler at Astro Info Service Ltd for supplying mission patches; INP Media Ltd for producing video grabs; Carole Ramsey and Sally Wortley for editorial assistance; Bob Bousfield and Jeff Carroll for DTP help.

Picture credits

(b=below, c=centre, fp=full page, l=left, r=right, t=top)
Cover, NASA; **2–3**, NASA; **4tl,** Getty Images; **4bl**, NASA; **4bc**, NASA; **5tl**, Science Museum/Science & Society Picture Library; **5cl,** NASA; **5c**, NASA; **5**, John Frassanito & Associates Inc; **6–7**, NASA; **8tc**, NASA; **8bc**, Bettmann/Corbis; **9c**, NASA; **10–11**, Getty Images; **12tl**, NASA; **12bl**, NASA; **12tr**, Science Photo Library; **12cr**, Science Museum/Science & Society Picture Library; **13t**, Western Reserve Historical Society; **13bl**, NASA; **13br**, Bettmann/Corbis; **14tr**, NASA; **14bl**, Mary Evans Picture Library; **14bc**, Mary Evans Picture Library; **14br**, Mary Evans Picture Library; **14–15c**, Mary Evans Picture Library; **15tr**, NASA; **15cl**, Mary Evans Picture Library; **16**, RIA Novosti/Science Photo Library; **17tr**, RIA Novosti/Science Photo Library; **17cr**, NASA; **17br**, Hugh Johnson; **18cl**, Bettmann/Corbis; **18bc**, NASA; **18–19c**, NASA; **19t**, Bettmann/Corbis; **19c**, NASA/Science Photo Library; **19b**, Hugh Johnson; **20tl**, Austrian Archives/Corbis; **20bl**, NASA; **20bc**, Hulton Archive/Getty Images; **20br**, UFA/The Kobal Collection; **20–21t**, Akg-Images, London; **21tr**, Bettmann/Corbis; **21br**, Hulton-Deutsch Collection/Corbis; **22l**, RIA Novosti/Science Photo Library; **22tr**, Science Museum/Science & Society Picture Library; **22br**, V2rocket.com; **23bc**, RIA Novosti/Science Photo Library; **23r**, Hugh Johnson; **23tl**, NASA; **24tl**, Detlev van Ravenswaay/Science Photo Library; **24bl**, V2rocket.com; **25–25c**, NASA; **25c**, Science Museum/Science & Society Picture Library; **25bc**, V2rocket.com; **25tr**, Julian Baum; **25br,** Science Museum/Science & Society Picture Library; **26tl**, Hulton-Deutsch Collection/Corbis; **26b**, NASA; **27tl**, FoxPhotos/Getty Images; **27r**, Images de Dora, Le Maner & Sellier; **27b**, Images de Dora, Le Maner & Sellier; **26–27c** V2rocket.com; **28tl**, Nina Leen/Pix Inc/Time Life Pictures/Getty Images; **28l**, V2rocket.com; **28bl**, V2rocket.com; **28bc**, V2rocket.com; **28br**, V2rocket.com; **28–29t**, Corbis; **29bl**, Imperial War Museum; **29br**, V2rocket.com; **29tr,** Bettmann/Corbis; **30tl**, NOAA; **30b**, NASA; **30–31t**, Akg-Images, London; **31tr**, NASA; **31cr**, Bonestall Space/NASA; **31bl**, NASA; **32tl**, RIA Novosti/Science Photo Library; **32b**, RIA Novosti/Science Photo Library; **32br**, RIA Novosti/Science Photo Library; **33l**, NASA; **33tl**, RIA Novosti/Science Photo Library; **33tr**, RIA Novosti/Science Photo Library; **33br**, Anatoly Zak; **34tl**, USAF; **34br**, Bettman/Corbis; **35r**, Anatoly Zak; **35r**, NASA; **36tl**, USAF; **36bl**, USAF; **36t**, USAF; **36tc**, USAF; **36c**, USAF; **36cb**, USAF; **36b**, USAF; **37t**, USAF; **37cr**, USAF/Air Force Flight Test Center History Office; **37br**, USAF; **38tl**, Bettman/Corbis; **38bc**, NASA; **38tr**, US Army; **38–39c**, NASA; **39tr**, RIA Novosti/Science Photo Library; **39b**, Terry Pastor (The Art Agency); **40–41**, NASA; **42bl**, Novosti; **42br**, Bettmann/Corbis; **42tr**, Hank Walker/Time Life Pictures/Getty Images; **43bc**, RIA Novosti/Science Photo Library; **43cr**, Nat Farbman/Time Life Pictures/Getty Images; **43bc**, Dmitri Kessel/Life Magazine/Copyright Time Life Pictures/Getty Images; **44bl**, NASA; **44bc**, US, Army; **44–45c**, NASA; **45tc**, NASA; **45br**, Hugh Johnson; **46bl**, Novosti/Science Photo Library; **46br**, Bill Bridges/Time Life Pictures/Getty Images; **46–47t**, Bettmann/Corbis; **47tc**, Blank Archives/Getty Images; **47tr**, Fox Photos/Getty Images; **47bc**, RIA Novosti/Science Photo Library; **48bc**, NASA; **48tr**, IMP BV; **49tl**, NASA; **49c**, NASA; **49tr**, NASA; **49bl**, NASA/Science Photo Library; **49b**, Hugh Johnson; **49br**, NASA; **50bl**, Keystone/Getty Images; **50br**, Hulton-Deutsch Collection/Corbis; **50–51t**, NASA; **51br**, Hugh Johnson; **52b**, Hugh Johnson (background)/Terry, Pastor (The Art Agency); **53t**, NASA; **53bl**, Novosti; **53br**, mentallandscape.com; **54bl**, Bonestell Space Art; **54br**, Andy Salmon; **54–55t**, Galaxy Picture Library; **55tc**, Galaxy Picture Library; **55tr**, Galaxy Picture Library; **55c**, Galaxy Picture Library; **55br**, NASA/Science Photo Library; **56b**, Genesis Picture Library; **56tr**, RAF; **57tc**, CNES; **57c**, SIRPA-ECPA 1995/ESA; **57bl**, Science Museum/Science & Society Picture Library; **57tr**, Anatoly Zak; **57br**, NASA/Science Photo Library; **58tr**, Bettmann/Corbis; **58bl**, Novosti; **58br**, Novosti; **59**, VideoCosmos; **60bl**, Novosti; **60bc**, Novosti; **60br**, Bettmann/Corbis; **60–61c**, Novosti; **61tc**, Bettmann/Corbis; **61br**, Novosti; **62cl**, Anatoly Zak; **62bl**, Anatoly Zak; **62c**, Anatoly Zak; **62tr**, RIA Novosti/Science Photo Library; **62br**, Hugh Johnson; **63l**, Hugh Johnson; **63tr**, Novosti-Kosmonautiki; **63c**, Anatoly Zak; **63cr**, Novosti-Kosmonautiki; **64tl**, Anatoly Zak; **64b**, VideoCosmos; **64–65b**, Anatoly Zak; **64tr**, Anatoly Zak; **65tl**, VideoCosmos; **65tc**, Anatoly Zak; **65tr**, Anatoly Zak; **65br**, Anatoly Zak; **66bl**, NASA; **66br**, NASA; **67**, NASA; **68l**, NASA; **68br**, NASA; **69t**, USAF; **69c**, NASA; **69bl**, NASA; **70tl**, NASA; **70l**, NASA; **70c**, NASA; **70bc**, NASA; **70br**, NASA; **70–71**, Julian Baum; **71tc**, NASA; **71tr**, NASA; **71br**, Hugh Johnson; **72–73**, NASA; **74tr**, NASA; **74bc**, NASA; **74–75c**, NASA; **75tr**, NASA; **75cr**, National Geographic Image Collection; **75br**, NASA; **76**, Novosti/Science Photo Library; **77l**, RIA Novosti/Science Photo Library; **77r**, Russian State Archive; **78tl**, Novosti; **78bl**, NASA; **78bc**, Roger Ressmeyer/Corbis; **78–79t**, Novosti; **78–79c**, Novosti; **78–79bc**, Novosti; **78–79b**, Novosti; **79bc**, Science Museum/Science and Society Picture Library; **79cr**, Novosti; **80bl**, Novosti; **80bc**, IMP BV; **80br,** Novosti; **80cr**, Novosti/Science Photo Library; **80–81tc**, Hulton-Deutsch, Collection/Corbis; **81bl**, Novosti; **81bc**, Novosti; **81br**, Bettmann/Corbis; **81tr**, Novosti; NASA; **82tr**, Ralph Morse/Time Life Pictures/Getty Images; **83**, Ralph Morse/Time, Life Pictures/Getty Images; **84tl**, Dean Conger/Corbis; **84l**, Ralph Morse/Time Life Pictures/Getty Images; **84cl**, Ralph Morse/Time Life Pictures/Getty Images; **84cr**, NASA; **84r**, NASA; **84–85tc**, NASA/Getty Images; **85bl**, NASA; **85br**, MPI/Getty Images; **86bl**, NASA; **86bc**, NASA; **86br**, NASA; **86tr**, NASA; **86–87t**, NASA; **87tr**, NASA; **87cr**, NASA; **87br**, NASA; **88**, NASA; **89tl**, NASA; **89bl**, NASA; **89tl**, NASA; **90–91**, NASA; **92bl**, Galaxy Picture Library; **92bc**, Galaxy Picture Library; **92tr**, NASA; **92–93t**, NASA; **93br**, NASA; **94tr**, NASA; **94cl**, NASA; **94br**, NASA; **94–95c**, Julian Baum; **95bl**, NASA; **95tr**, NASA; **95bc**, NASA; **95br**, NASA; **96br**, RIA Novosti/Science Photo Library, **96–97t**, RIA Novosti/Science Photo Library; **97cr**, Russian Space Archive; **97bc**, Novosti; **98tl**, NASA; **98bl**, Bettman/Corbis; **98tr**, NASA; **98br**, NASA; **99**, NASA; **100–101**, NASA; **102–103c**, NASA; **103tc**, Bettmann/Corbis; **103bl**, Bettmann/Corbis; **104tl**, AP/Empics, **104tc**, Novosti; **104–105c**, Bettmann/Corbis; **104tr**, AP/Empics; **105tl**, Novosti; **105tc**, Empics; **105tr**, Empics; **105cr**, Novosti; **105bl**, Time Life, Pictures/Getty Images; **105bc**, Rykoff Collection/Corbis; **106–107**, Bettmann/Corbis; **107t**, Bettmann/Corbis; **107bl**, Lynn Pelham/Time Life Pictures/Getty Images; **108–109**, NASA; **108bl**, NASA; **108tr**, Hugh Johnson; **109tl**, NASA; **109tc**, NASA; **109tr**, NASA; **110bl**, Time Life Pictures/NASA/Time Life Pictures/Getty Images; **110r,** NASA; **111t**, NASA; **111bl**, NASA; **111bc**, NASA; **111br**, NASA; **112tr**, NASA; **112bl**, NASA; **112bc**, NASA; **112br**, NASA; **113t**, NASA; **113bl**, NASA; **113cr**, NASA; **113br**, NASA; **116tr**, NASA; **116b**, NASA; **117t**, NASA; **117b**, Peter Bull; **118l**, NASA; **118tr**, NASA; **118br**, NASA; **119tr**, NASA; **119bl**, NASA; **119br**, NASA; **120cl**, NASA; **120tc**, NASA; **120tr**, NASA; **120c**, NASA; **120cb**, NASA; **120br**, NASA; **121tl**, NASA; **121c**, NASA; **121br**, Galaxy Picture Library; **122–123t**, Terry Pastor (The Art Agency); **122bc**, NASA; **122br**, Genesis Picture Library; **123cl**, NASA; **123bl**, NASA; **124tl**, NASA; **124tr**, NASA; **124c**, NASA; **124bl**, NASA; **124br**, NASA; **124–125c**, Julian Baum; **125tl**, NASA; **125tr**, NASA; **125bl**, NASA; **125bc**, NASA; **126bl**, Dean Conger/Corbis; **126r**, Edwin Cameron/Energia; **127tl**, Hugh Johnson; **127tr**, Novosti/Science Photo Library; **128l**, Novosti; **128tr**, Anatoly Zak; **128br**, Anatoly Zak; **129tl**, Novosti; **129tr**, Novosti; **129bl**, NASA; **129br**, Novosti; **130tc**, Anatoly Zak; **130tl**, Anatoly Zak; **130br**, Anatoly Zak; **130–131**, Chris Taylor; **131cl**, VideoCosmos; **131bl**, Anatoly Zak; **131tr**, VideoCosmos; **131cr**, VideoCosmos; **132bl**, NASA; **132cl**, NASA; **132br**, NASA; **133tr**, NASA; **133tl**, NASA; **133tr**, NASA; **133bl**, Ralph Morse/Time Life Pictures/Getty Images; **133c**, NASA; **133br**, NASA; **134tl**, NASA; **134bc**, NASA; **135bl**, NASA; **135bc**, NASA; **135br**, NASA; **136bl**, NASA; **136tr**, NASA; **137t**, NASA; **137bl**, NASA; **137bc**, NASA; **137br**, NASA; **139–139**, Time Life Pictures/NASA/Getty Images; **140b**, Galaxy Picture Library; **140bc**, NASA; **140rt**, NASA; **140rtc**, NASA; **140rc**, NASA; **140rcb**, Getty Images; **140rb**, NASA; **141tc**, NASA; **141cr**, NASA; **141br**, NASA; **142tr**, NASA; **142bl,** NASA/Galaxy Picture Library; **142bc**, NASA; **142br**, NASA; **143t**, NASA; **143br**, NASA; **144tl**, NASA; **144bl**, Science & Society, Picture Library; **144tr**, NASA; **145tl**, NASA; **145bl**, NASA; **145cr**, NASA; **145br**, NASA; **146br**, NASA; **148tc**, NASA; **148bl**, NASA; **149tl**, NASA; **149tr**, NASA; **149cr**, NASA; **149b**, Chris Taylor; **150–151t**, NASA; **150bl**, NASA; **150cl**, NASA; **150bc**, NASA; **150cr**, NASA; **150bl**, NASA; **151tr**, NASA; **151cr**, Ronald Grant Archive; **152–153**, NASA; **153c**, NASA; **153t**, NASA; **153b**, NASA; **154tl**, NASA; **154bl**, NASA; **154br**, NASA; **155**, NASA/Science Photo Library; **156tr**, NASA; **156cl**, NASA; **156c**, NASA; **156–157b**, NASA; **157tr**, NASA; **158tl**, NASA; **158cl**, NASA; **158–159**, Julian Baum, **159tl**, NASA; **159tc**, NASA; **159bc**, NASA; **159tr**, NASA; **159c**, Julian Baum; **159bc**, Julian Baum; **159br**, Julian Baum; **160–161**, NASA; **162–163**, Corbis; **162tr**, NASA; **162bc**, NASA; **163t**, NASA; **163bl**, NASA; **163cr**, NASA; **164bl**, NASA; **164–165**, NASA; **165tr**, NASA; **165cr**, NASA; **165br**, Galaxy Picture Library; **166tl**, NASA; **166tc**, NASA; **166tr**, NASA; **166bl**, NASA; **166bc**, NASA; **166br**, NASA; **167tl**, NASA; **167tc**, NASA; **167tr**, NASA; **167bl**, NASA; **167bc**, NASA; **167br**, NASA; **166–167b**, NASA; **168–169**, Science Museum/Science & Society Picture Library; **170tr**, NASA; **170c**, NASA; **170bl**, AP/Empics; **170br**, NASA; **171l**, NASA; **171tr**, NASA; **171cr**, NASA; **171br**, NASA; **172tc**, NASA; **172cl**, NASA; **172–173**, Hugh Johnson; **172br**, NASA; **173tc**, NASA; **173cr**, NASA; **173bl**, NASA; **173bc**, NASA; **173br**, Science & Society Picture, Library; **174tr**, NASA; **174c**, NASA; **175tl**, NASA; **175cl**, NASA; **175tr**, Novosti; **175br**, RIA Novosti/Science Photo Library; **176tl**, NASA; **176bl**, Arthur Rothstein/Corbis; **176tr**, AFP/Getty Science & Society Picture Library; **176cr**, NASA; **176c**, Bettmann/Corbis; **176bc**, NASA; 176br, Bettmann/Corbis; **177t**, NASA; **177br**, NASA; **178tl**, Bettmann/Corbis; **178bl** Eric Preau/Sygma/Corbis; **178–179b**, Novosti; **179tl**, VideoCosmos; **179tr**, Novosti; **179br**, James Oberg; **180bl**, Anatoly Zak; **180br**, Anatoly Zak; **180tr**, Anatoly Zak; **180–181b**, VideoCosmos; **182bl**, James Oberg; **182bc**, James Oberg; **182tr**, Novosti; **183t**, Novosti; **183c**, Corbis; **183br**, Novosti; **186–187**, NASA; **188cl**, Molniya; **188tr**, NASA; **188bl**, BAE Systems; **188–189b**, NASA; **189fp**, USAF; **189br**, NASA; **190bl**, NASA; **190b**, NASA; **190r**, Julian Baum; **190–191t**, Adrian Thompson; **191bl**, NASA; **191bc**, NASA; **191br**, NASA; **192bl**, NASA; **192b**, NASA; **192tr**, NASA; **192–193c**, NASA; **193tr**, NASA; **193br**, NASA; **194bl**, Science & Society Picture Library; **194tr**, NASA; **194–195**, NASA; **195tr**, NASA/Science Photo Library; **196cr**, Corbis; **196bl**, NASA; **196bc**, NASA; **196–197c**, Julian Baum; **197tc**, NASA; **197cr**, NASA; **198bl**, AP/Empics, **198br**, ESA; **198tr**, NASA; **199tl**, NASA/Science Photo Library; **199tr**, Bettmann/Corbis; **199bl**, AP/Empics; **199br**, Ed Kolenovsky/AP/Empics; **200bl**, NASA; **200tr**, Science & Society Picture Library; **201fp**, NASA; **201bl**, NASA/Science Photo Library; **202–203**, NASA; **202bl**, NASA/Getty Science & Society Picture Library; **203cl**, NASA/Science Photo Library, **203bl**, NASA; **203tr**, Diane Walker/Time Life Pictures/Getty Science & Society Picture Library, **204tl**, NASA; **204bl**, Bettmann/Corbis; **204bc**, Bettmann/Corbis; **204cb**, Time Life Pictures/NASA/Getty Science & Society Picture Library; **204br**, NASA; **204tr**, Bettmann/Corbis; **204–205c**, Corbis; **205bl**, Space Frontiers/Hulton Archive/Getty Science & Society Picture Library; **205cr**, Corbis; **206tl**, NASA; **206–207b**, NASA; **207tr**, NASA; **207tl**, Time Life Pictures/NASA/Getty Science & Society Picture Library; **207br**, NASA; **208–209**, NASA; **210bl**, VideoCosmos; **210tr**, Detlev van Ravenswaay/Science Photo Library; **210br**, VideoCosmos; **211**, VideoCosmos; **212cl**, Novosti; **212–213**, Ian Palmer; **213tr**, NASA/Time Life Pictures/Getty Science & Society Picture Library; **213cl**, VideoCosmos; **214–215**, Molniya; **215tl**, Molniya; **215c**, Novosti; **215br**, Molniya; **215bl**, Molniya; **216tl**, NASA; **216tr**, NASA; **216cl**, NASA; **216bl**, NASA; **216br**, NASA; **217tl**, NASA; **217bl**, NASA; **217tr**, Novositi; **218–219**, NASA; **220tl**, Reuters/Corbis; **220tr**, Empics; **220br**, Reuters/Corbis; **221**, NASA/Science Photo Library; **221br**, NASA; **222tl**, NASA; **222bl**, NASA; **222bc**, NASA; **222tl**, NASA; **222cl**, NASA; **222c**, NASA; **222bc**, NASA; **222br**, NASA; **223t**, NASA; **223br**, NASA; **224tl**, NASA; **224tr**, NASA/Science Photo Library; **224bc**, NASA; **224br**, Robert, McCullough/Dallas Morning News/Corbis; **224–225t**, NASA; **225br**, NASA; **226–227**, NASA; **228c**, ESA; **228–229b**, ESA; **228–229c**, CNES; **229cl**, ESA; **229tr**, ESA; **230bl**, ESA; **230bc**, ESA; **230tr**, Tony Ranze/Getty Science & Society Picture Library; **231l**, ESA; **231br**, ESA; **232tl**, ESA; **232tc**, Safran; **232–233c**, Adrian Thompson; **232bc**, Ariane Space; **233bl**, Ariane Space; **234bl**, VideoCosmos; **234tr**, Courtesy of JAXA; **234cr**, Courtesy of JAXA; **234–235b**, Courtesy of JAXA; **235tl**, Courtesy of JAXA; **235tr**, STR/AFP/Getty Science & Society Picture Library; **236**, Roger Ressmeyer/Corbis; **236tl**, Stefan, R. Landsberger/International Institute of Social History, Amsterdam; **237tr**, Bettmann/Corbis; **237bl**, Reuters/Corbis; **238tc**, Canadian Space Agency; **238bl**, Art Directors/Dinodia; **238br,** Indian Space Research Organisation; **238–239c**, Indian Space Research Organisation; **239tr**, Reuters/Eric, Sultan/Corbis; **239br**, AEB/EPA/Corbis; **240tl**, Empics; **240cl**, NASA; **240bl**, NASA; **240tr**, Hulton-Deutsch, Collection/Corbis; **240br**, NASA; **241**, Canadian Space Agency; **242–243**, Reuters/Corbis; **244tr**, Camera Press/ITAR-TASS, **244bl**, Peter Bull; **244–245t**, NASA/Science Photo Library; **245br**, NASA; **246bl**, Luis Enrique Ascui/Getty Science & Society Picture Library; **246tr**, ESA; **246–247t**, ESA; **247bl**, Andrew Fox/Corbis; **247cr,** Keystone/Getty Science & Society Picture Library; **247bc**, Peter Bull; **248tl**, Courtesy of GeoEye; **248tr**, Courtesy of GeoEye; **248cl**, USGS; **248bc**, NOAA/Science Photo Library; **248br**, NASA; **249tc**, NASA; **249br,** NASA; **250bl**, Corbis; **250bc**, Caltech; **250tr**, NASA; **250cr**, NASA; **251t**, NASA; **251tr**, ESA/NASA; **251c**, NASA; **251bc**, ESA; **252bl**, NASA; **252tr**, Al Fenn/Time Life Pictures/Getty Science & Society Picture Library; **253tr**, NASA; **253br**, NASA; **254–255**, NASA; **255tr**, NASA; **255bl**, NASA; **256bl**, NASA; **256bc**, NASA/JPL-Caltech; **256br**, NASA; **256–257c**, NASA; **257tl**, MPE; **257tc**, GALEX; **257cr**, DSS/Galaxy Picture Library; **257tr,** Philip, Perkins/Galaxy Picture Library; **257cl**, IRAS, **257c**, NASA/JPL-Caltech, **257rc**, ESA; **257r**, Rainer Beck/Philipp Hoernes/MPIfR; **257bc**, STScI; **257br**, NASA/ESA/JHU/R. Sankrit & W. Blair; **258bl**, RIA Novosti/Science Photo Library; **258tr**, BMDO/NRL/LLNL/Science Photo Library, **259tl**, NASA; **259tr**, NASA/Science Photo Library; **259b**, NASA; **260l**, NASA; **260tr**, Science & Society Picture Library; **260bc**, Peter Bull; **260–261t**, NASA; **261tc**, NASA; **261tr**, Novosti/Science Photo Library; **261br**, Novosti; **262c**, NASA; **262–262b**, NASA; **262cr**, NASA; **262–263t**, NASA; **263tr**, NASA/Science & Society Picture Library; **264tr**, NASA; **264bl**, NASA; **264bc**, NASA; **264–265t**, NASA; **265bl**, NASA; **265br**, Peter Bull; **266bl**, Corbis; **266br**, NASA; **266tr**, Roger Ressmeyer/NASA/Corbis; **266–267t**, NASA; **266–267b**, BP/NRSC/Science Photo Library; **267cr**, NASA; **268tl**, US Naval Observatory/Science Photo Library; **268cl**, NASA/Science Photo Library; **268–269c**, Hugh Johnson; **268br**, NASA; **269tl**, TLP/NASA/Getty Science & Society Picture Library; **269tc**, NASA; **269tr**, NASA; **269r**, Dan Groshong/AFP/Getty Science & Society Picture Library; **269bl**, IMP BV; **269c**, NASA; **269br**, NASA; **270tl**, NASA; **270tr**, NASA/Galaxy Picture Library; **270bl**, NASA; **270–271b**, NASA/Galaxy Picture Library; **271t**, NASA; **271br**, NASA; **272–273b**, NASA; 272cr, Peter Bull; **272–273tc**, ESA/Science Photo Library; **273cl**, Detlev van Ravenswaay/Science Photo Library; **273tr**, ESA; **273br**, NASA; **273bc**, ESA; **274tl**, NASA; **274bc**, Science Museum/Science & Society Picture Library; **274–275b**, NASA; **275tl**, ESA; **275tr**, ESA; **275c**, ESA; **276cl**, NASA; **276bl**, NASA; **276–277c**, Julian Baum; **277tl**, NASA; **277tr**, NASA; **277cr,** NASA; **277br**, NASA; **277bl**, NASA; **278tl**, NASA; **278b**, NASA; **278tr**, ESA; **279tl**, Science & Society Picture Library; **279tr**, Peter Bull; **279bl**, NASA; **279br**, NASA; **280tl**, NASA; **280cl**, NASA; **280–281**, NASA; **282tl**, ESA; **282tr,** NASA; **282c**, NASA; **282bc**, Hugh Johnson; **283**, NASA; **283tl**, NASA; **284**, NASA/John Frassanito & Associates/Hugh Johnson; **286bl**, NASA; **286tr**, NASA; **286cr**, NASA; **287t**, NASA; **287br**, RKK Energia; **288–289**, Hugh Johnson; **290tr**, NASA; **290c**, NASA; **290bl**, NASA; **290br**, NASA; **290–291t**, NASA; **291tr**, NASA; **291bc**, NASA; **291br**, NASA; **292tr**, NASA; **292cr**, NASA; **292–293**, NASA; **294tl**, NASA; **294cr**, NASA; **294bl**, NASA; **294bcl**, NASA; **294bc**, NASA; **294bl**, NASA; **295tr**, NASA; **295br**, NASA; **294–295t**, NASA; **296tl**, NASA; **296tr**, NASA; **296cl**, NASA; **296cr**, NASA; **296b,** NASA; **297tl**, NASA; **297c**, NASA; **297bc**, Time Life Pictures/NASA/Getty/Science & Society Picture Library; **298tc**, Joshua Hildwine, through Dan Johnson, Luft46.com; **298b**, NASA; **299tl**, NASA; **299c**, NASA; **299tr**, Genesis Picture Library; **299bc**, NASA; **299b**, Peter Bull; **300–301**, China Foto Press/Getty Science & Society Picture Library; **301tl**, AP/Empics; **301tr**, China, Photos/Getty Science & Society Picture Library; **301cr**, Li Gang/China Features/Corbis; **301bl**, Li Gang/China Features/CORBIS; **302tr**, NASA; **302tc**, Brooks Kraft/Corbis; **302bl**, NASA; **302bc**, NASA; **302br**, NASA; **302–303bl**, John Frassanito & Associates Inc; **303tl**, NASA; **303tr**, NASA; **304tl**, ESA; **304tr**, NASA; **304br**, NASA; **305tl**, NASA; **305cr**, Martin Bond/Science Photo Library; **305b**, NASA; **306br**, NASA; **306tr**, NASA; **306br**, Bettmann/Corbis; **306–307t**, NASA; **307tr**, NASA; **307bl**, NASA; **307bcl**, NASA; **307br**, NASA; **308bl**, Starchaser Industries Ltd; **308bc**, Bristol Spaceplanes Ltd; **308tr**, Hugh Johnson; **309t**, Mike Masse; **309cl**, Seymour Powell; **309bc**, Sergei Ilnitsky/Corbis; **309br**, Robyn Beck/AFP/Getty Science & Society Picture Library; **310–311tr**, NASA; **310tr**, NASA/Ames Research Center; **310bl**, Space Studies Institute; **311br**, British Interplanetary Society.

Every effort has been made to trace the copyright holders. Dorling Kindersley apologizes for any unintentional omissions and would be pleased, in such cases, to add an acknowledgement in future editions.

"Walking on the Moon was **a piece of cake**. It was easy. But getting to the Moon was anything but easy" – *Buzz Aldrin*

Discover more at
www.dk.com

ISBN 978-1-4053-1818-1

9 781405 318181